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Thesis for a Bachelor of Philosophy Degree

**Environmental Impacts of Renewable Energy:
a literature review**

Alexander David Clarke. January 1995

Faculty of Technology

Technology Policy Group, Open University.

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Abstract

Environmental Impacts of Renewable Energy: a literature review

A selection of the literature describing the environmental impacts of eight different renewable energy sources is reviewed; hydro, biomass, geothermal, wind, tidal, solar, wave and ocean thermal.

The importance and status of environmental impacts to renewable energy sources is discussed and the character of the literature is considered. Starting with hydro electric power, the literature encompasses different perspectives; advocates of expansion of HEP due to its environmental advantages, or those stressing ecological and geomorphological impacts on flora, fauna. Some reviews concern environmental protection policy, involving tradeoffs, policy choices and bargaining. The environmental impacts of various sources of biomass such as forestry, agriculture, domestic and industrial wastes, and biofuels are reviewed. Biomass production and conversion is covered through assessment of soil resources and net energy output, energy forestry impacts, pollution from combustion, improved technologies such as gassification, and incineration of wastes and landfill gas. Geothermal energy's impacts are discussed through reviewing literature concerning air, water, seismicity, and noise pollution, land use, subsidence and some protection policy developments. The impacts of wind energy are similarly covered by topic: visual impact, noise, safety, electromagnetic interference, wildlife, land use, public acceptability and planning. Several works on tidal energy are reviewed including most of the existing tidal energy plants, in terms of impact on flora, fauna, water quality, sediments, drainage and flooding. Solar energy's impacts are considered for the various different technologies; passive, thermal, concentrator, photovoltaic, and the impacts of manufacturing. Some studies of potential impacts from wave energy have been reviewed and one of ocean thermal energy. A chapter reviews the general renewable environmental impact literature, and another provides a brief overview of the valuation and costing of impacts. The final chapter considers the role and effects of environmental impact studies on the development of the technology.

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Environmental Impacts of Renewable Energy: a literature review

This dissertation reviews the literature of the environmental impact of using renewable energy sources, technology by technology.

While renewables may well have lesser environmental impacts than fossil fuels in many respects, eg emissions and waste products, the existing literature shows that they have other impacts of a different nature. Comparisons between the environmental impacts of different renewable and fossil sources need to be made but cannot without a structure that employs common measures and provides a model for understanding. The existing approaches to environmental impact do not readily provide such a coherent structure. From the existing literature, the beginnings of some common themes to provide a structure can be proposed.

Literature Review

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Chapter 1.

Introduction

Both renewable energy sources and their technologies are extremely diverse and there are considerable difficulties in comparing different renewable energy technologies and sources.

Importance of Environmental Impacts to Renewable Energy

Environmental Impacts are important to the development of renewable energy due to the intimate association of renewable energy technologies with natural energy flows. There are at least five main reasons for this:

1. Renewable Energy Sources are obtained from natural energy flows in the environment. These flows power the natural environment and are often important to the maintenance and functioning of those environments. Abstracting energy from natural energy flows can in some cases modify them and change their character.
2. Renewable Energy technologies often harness diffuse energy flows and so require a large numbers of collectors distributed across large areas. This can be a source of considerable impact to the environment.
3. Renewable Energy sources are specific to the sites where they occur and cannot necessarily be found at other sites. The environmental impacts incurred by renewable energy technologies will also tend to be specific to those sites.
4. The use of Renewable Energy sources will be limited by the capacity of the environment to accommodate any impacts, as well as by the available energy.
5. Renewable Energy sources have the advantage of being 'clean' with no (or in some cases few) emissions and are justified on the basis of their environmental advantages.

Definition of the Environment

The term environment is generally used for the surroundings, or conditions, the spatial context, and the outside links, biologically and physically, to the wider world. However, the environment is not one thing, -it can be divided into at least three basic components for the purposes of impact assessment.

- i) The Natural Living Environment
- ii) The Natural Inanimate Environment
- iii) The Human or Cultural Environment

-i)The Natural Living Environment

This is comprised of Flora and Fauna as it exists independent of human activity. It requires energy to fuel its growth and maintenance, in addition to the maintenance of climatic, soil and water conditions within a certain range. The activities of flora and fauna help to create and influence these conditions.

ii)The Natural Inanimate Environment

This consists of the earth's surface, the oceans and the atmosphere, which are acted upon by energetic processes. The action of energy on the earth's surface is known as geomorphology, and on oceans and the atmosphere oceanology and meteorology respectively. These processes are an important factor in the morphology of landscapes, eg the hills and valleys, and also the maintenance of soil and aqueous conditions. Energy flows contribute to the shape of shorelines, beaches and marine conditions. They can be important to the continuation of existing shore lines and other features.

-iii) The Human or Cultural Environment

This category includes firstly human activities on the environment to cultivate wild areas changing them into for example, agricultural land, forestry plantations or urban environments. Managed landscapes are achieved through such means as drainage works, earth moving or changing the vegetation.

Secondly, human need for certain minimum environmental standards of air and water quality, noise and light requirements is included here.

Thirdly, under this category come human aesthetic notions about the environment such as the value of landscapes or certain features in the landscape.

Definition of Environmental Impact

The term environmental impact has been defined and used in various ways. One UK. Department of the Environment Report on Environmental Impact Analysis, drew a distinction between environmental *effects* and environmental *impacts* (Catlow 1976). It stated that while effects are the physical and natural changes resulting directly or indirectly from development, the impacts are the consequences or end products of those effects, represented by attributes of the environment on which we can place an objective or subjective value. This usage of the term is not quite that employed in this thesis. Although distinguishing between environmental effects and impacts conveys an idea of precision, in practice it is difficult to draw the boundary lines.

Another term that may require definition is 'Environmental Stress', which has been described as 'any force that pushes the functioning of a system or subsystem beyond its ability to restore its former structure and function', (Meir 1972 cit. in Petts 1984).

In this thesis the term Environmental Impact is used in the sense of changes to environmental conditions and is close to environmental effects, both of which should be amenable to some form of measurement. The subject of valuation is pursued later on in chapter 9. Impacts, as used here, are not in themselves necessarily either detrimental or

beneficial. However, the uncertainty about the effects of these changes leads to a presumption, by environmentalists, in favour of the status quo, and impacts are usually viewed with suspicion.

The degree, the rate, and frequency of change are important variables when measuring environmental impact.

The significance of the changed conditions and their role in particular environments and ecological systems needs to be discovered. Any conditions that are critical to the functioning of ecosystems or whole environments need to be identified.

Classification of the Literature

The literature is reviewed by technology in order of installed power and output used, starting with Hydro Electric Power. Although the exploitation of biomass is nominally greater, most of its use is represented by traditional cooking and heating purposes in rural areas. This review is mainly concerned with the generation of electricity from renewable energy, rather than production of heat or light.

This order has been adopted for the reason that, at the present time, the greatest environmental impact in total, from modern renewable energy production, may be associated with the technologies most used. An alternative ranking might be by the size of the different renewable energy flows, solar, wind, hydro, ocean currents, etc. However, this type of ranking would not reflect current renewable energy use and hence current environmental impacts. It might not reflect potential impacts either, since technologies might never be fully exploited for some of the sources, and in addition, the size of the resource may be only one factor out of many, related to the impact.

For some of the technologies, the reviews are chronologically ordered with the early works first. The reason for this ranking is to enable the evolution of the subject of environmental impacts to be traced. The rapid technical development of some of the renewables, is another reason for chronological ordering. However, for some technologies (wind and geothermal) where there is a substantial amount of complex data, this scheme was not adopted and the review is structured by topic. Other methods of organising the literature by type or source, eg engineering, academic, economic, environmental, etc, have not been employed. Such issues are however mentioned and discussed in the conclusions.

Themes

Some of the themes explored in this review are listed below.

1. What is the importance of environmental impacts in the development of renewable energy technology and its exploitation ? Were environmental impact studies led by technology, environmental concerns, economic issues, policy issues, resource studies or academia ? For example what effect did greenhouse effect and global warming fears have on the literature?

Do common themes link the different examples of the literature?

How important are environmental impacts to the individual renewable energy technologies? If there are differences in the importance to each does the literature show this?

Another consideration is how the literature changed in character over the years in response to the development of technology or lack of development. What has been the effect of the pace of technological change ?

What is the purpose of the literature? Given that there may be different motivations for the development of renewable energy sources, eg at different times and in different countries, are environmental issues leading the development, or even very significant ?

Who the authors and the commissioners of the literature are and how this has influenced its character, is discussed below.

Technology

Environmental impacts are also dependent on the technology employed. Since renewable energy is a fast developing, novel and highly diverse field, even for a single renewable source, a variety of different types of technology may be employed. Therefore short descriptions of the technology employed are included.

Thesis Structure

Chapters 2-7 review the *physical* impacts of renewable energy technologies and some of the social impacts. Chapter 8 reviews some of the literature comparing impacts from all the renewables. In order to begin to consider how these environmental impacts are taken into account in energy policy, chapter 9 briefly reviews some literature of the main methods of valuation of environmental impacts from energy sources. Chapter 10 draws conclusions on the main impacts from each source and the effect this has had on the development of the technology and on energy policy in general.

The coherence and significance of the body of knowledge on environmental impacts and its applicability to methods of valuation are discussed.

Selection

The literature reviewed represents a selection of a now very extensive literature, on the basis of it being a representative sample, its significance, succinctness, and originality or due to the recognition accorded to the work. The selection reviewed does not attempt to provide comprehensive coverage of the subject due to the volume of literature available. Instead, the aim is an annotated guide and review of *key* issues.

The criteria for the selection of these issues are based on the extent to which the literature describes and explains the processes leading to environmental impact, making them amenable to analysis. This is a review of academic reports on impacts not a review of processes for assessment or decision making except for those involving information on impact eg environmental impact statements. The review does not cover public attitude research of which there is a growing literature, eg Barac, Spencer, Elliott (1983), or Elliott (1994).

Chapter 2

Hydro Electric Power

Introduction

Hydro Electric Power (HEP) is the most exploited of the renewable energy sources for generating electricity, with a total world capacity of 549.2 GW installed, which contributed 14.5% of the world's electricity in 1986. (Johansson, et al 1993) The economic potential for hydro electricity may be between 6000-9000 TWh per year of which only about 2000TWh has so far been developed. (Johansson et al 1993).

HEP is also the oldest as well as most widely used of the renewable energy sources for generating electricity and as such a considerable amount of work has been carried out on its environmental impacts.

However, awareness of environmental impacts from hydro electric generation may be thought to have arrived late -up to fifty years after hydro schemes were first built. In view of the considerable changes that hydro schemes impose on river systems, this may seem surprising but many early schemes were built before mass environmental awareness existed. For example many schemes were built in the years between the wars, when the economic advantages may have seemed irresistible. Comparisons with coal fired power generation may have made HEP seem impact free. Local loss of fisheries or other longer term problems did not feature in assessment of projects. At the time, the fewer generation options available may have contributed towards this perception. Furthermore the lengthy timescale needed for many of the impacts to appear provides another explanation for the lack of awareness.

Literature Review

1. Deudney

An upbeat assessment of hydro electric power's prospects by Deudney in 1981, in Worldwatch Paper 44 *'Rivers of Energy : The Hydropower Potential'*, suggests the possibility of a four to six fold increase in capacity (at the time) despite environmental and economic constraints (Deudney 1981'). The US based Worldwatch Institute, is an influential independent research organisation focussing on global problems and is funded by private and UN organizations. This 55 page paper in booklet form, conveys a broad view of hydropower's potential and problems. Deudney discusses a range of economic, policy, developmental, environmental, social and institutional issues in a non technical manner. Stating that hydropower has environmental advantages compared to oil, coal and nuclear he does acknowledge that large dams can cause environmental damage if not properly planned. He believes the advantages of hydro, -stable prices and permanence are not given sufficient attention and "environmental concerns are too often neglected both in choosing between hydro and thermal power plants and in implementing hydropower projects." Deudney exhorts greater use of untapped hydropower resources in a well managed form for the longer term. However, his view that hydro electric power is the only proven renewable energy source, even in 1981, seems odd given that both biomass and geothermal were well established by then.

Deudney states that "the ecological changes wrought by large dams bring both opportunities and dangers" changing self regulating ecosystems into ones that must be managed. Some problem issues he cites are: sedimentation at eg Sanman Gorge Dam on Yellow River in China, soil erosion eg in Nepal, and the effects of irrigation on food supply. An example of changes to fisheries he cites, is the destruction of the Eastern Mediterranean sardine fishery by the Aswan dam which had the effect of substituting 18,000 tons of sardine harvest with 20,000 tons of Lake Nasser fish. Other environmental problems he discusses are health impacts, relocation of indigenous populations, and habitat loss through inundation.

Deudney advocates increased reliance on small scale hydro, especially in developing countries. He notes that the location of most of the large hydro potential is in remote undeveloped regions, although he does not suggest any particular link sensitivity to environmental impacts.

To avoid the extra impacts of new dams and growing public opposition to new dam construction, he recommends better use of existing dams.

Deudney notes that the US and Sweden have been leaders in preserving ecologically significant rivers. As an example he notes that 39 rivers in the US, with 9 GW of HEP potential, are protected under the Wild and Scenic Rivers Act. Deudney states that although potential dam sites will become more attractive in the future, closer scrutiny will be given by officials and public. "Since power sales can seldom justify a project, the often inflated claims of recreational and flood control benefits must be assessed carefully." "In many cases the expected benefits of a project,...could be better achieved by reducing water waste and by discouraging construction in flood plains." Better use of existing small dams and upgrading and refurbishing larger dams are encouraged by him.

He points out the tendency by international lending agencies to rely on large dams only, and stresses the need to allocate funds for reforestation and ecological issues, warning that "unless a broad view of water development is taken, the benefits of hydroelectric projects will come at the expense of the environment and the poorer groups in developing societies."

Deudney concludes that "Hydro development will have substantial long term impacts on the global environment as well as the world economy and is a "non polluting source of energy, desperately needed as the curtain falls on the petroleum age",.... which "gives to, rather than takes from the future."

The complexity of aquatic environments with interlinking physical, chemical and biological processes is brought out by various works in the literature.

2. Gras

Gras outlines the complex interrelationships of factors influencing water quality resulting from hydraulic projects including dams reservoirs and hydro electric turbines in a clear manner in a paper titled *The effects of hydraulic projects and their management on water quality*'.(Gras, et al 1983). He writes from the position of the Department of the Aquatic and Atmospheric Environment of the Research Department of Electricite de France, using largely French examples and references. Gras summarises interactions of both the physical parameters which alter water quality and the ecosystem, emphasising that the physico

chemical and biological aspects cannot be separated. The important physical parameters he considers are changes in the flow rate, in depth, water residence time in reservoirs, and thermal behaviour. The reserve, or minimum flow, is he states, particularly important for maintenance of ecological functions. He covers the oxygen, nitrogen, and other chemicals balance with its important effects on plankton and fish as well as the effects of sediment transport rate and turbidity -light penetration. Gras describes the general effects from river modification such as dams, weirs, canalization and by-pass reaches. The effects of flow control, reservoirs, and pumped storage on both physical and aquatic life are included. He states that all hydraulic projects have a definite effect on the quality of water, but appropriate design or good management of a facility can limit a particular effect on the water quality, although it is necessary to have criteria to follow. "The criteria relating water quality differ from one use to another, and even for the same application various criteria may be in conflict", he states. Mathematical models allow analysis of these problems so that the effects can be estimated or the design improved or management regimes selected, though he admits that the scope for adapting management to meet water quality objectives may be limited. Gras states that "the greatest change is undoubtedly caused by the creation of large reservoirs."

Two major works on the environmental impacts from hydro electric power are reviewed below, both covering ecological aspects of hydro electric power / impoundment. Both works were written at about the same time and have similar approaches to the subject. Describing the subtle and almost infinitely varied processes that occur in ecology is difficult, and while Langford sticks to descriptions of the more basic and general processes, Petts covers a more comprehensive subject range and provides an enormous number of examples and instances. Unfortunately this may muddy the waters to some extent since Petts always appears to be able to cite a counter example; a river behaving in the opposite manner to that predicted. This does serve to illustrate the complex and dynamic nature of rivers, -in all aspects, physical, chemical and biological, all interdependent factors.

3. Langford

'Electricity Generation and the Ecology of Natural Waters', (Langford 1983) is an academic text of 342 pages on the chemical and ecological effects of electricity generation covering flora and fauna and biochemical effects, but not geomorphological aspects. This is a substantial work covering all of the traditional forms of generating electricity, including fossil and nuclear as well as hydro electric power, pumped storage and tidal. Only about 70 pages cover the topic of hydro electric power directly, since much of the book is devoted to the ecological effects of the use of water for cooling thermal plant and the effects of anti fouling chemicals or pollution effects from thermal plant and other discharges.

Langford states that electricity generation is the largest single user of water at the time of writing, representing 50% of total water demand. "The massive dams necessary to impound rivers and provide the hydrostatic head for hydro electricity developments have blocked the passage of migrating fishes and created long, deep, stratified lakes where once

flowed fast, shallow turbulent streams." He states that HEP developments always involve physical alterations in the relevant aquatic habitats, but that "in many cases these may lead to social benefits which can offset any deleterious ecological effects."

Ecological Awareness

Development of ecological concern in the past two decades (prior to 1983) is reflected in legislation, research and the media, he states in Chapter 1. Langford notes that for centuries it has been known that obstructions in rivers block the passage of migratory fish, but even so there is still controversy over dams and weirs in salmon rivers. Research on salmonids and the effects of hydro schemes has, Langford states, been carried out in Scotland since the late 1940's, and research was also carried out in Sweden, USA, and the USSR. However, he notes that "dams without provision for fish passage were still being built in some countries until quite recent times", eg in the USA and Canada, where controversy about high dams continues.

Water Movement

"Water movement is one of the main factors in shaping biocoenoses, (biological communities) whether the flow of rivers or action of waves, upon shore, because of its effect on the substratum," states Langford. He quotes Hynes: "In tidal and in lake waters it is vital in forming the shore topography and substratum and hence the composition of the flora and fauna". Also he notes that below 20cm s^{-1} water movement, silt and mud will settle out, while at velocities of $20\text{--}40\text{cm s}^{-1}$, stream beds would comprise sand among the stones and gravel. He describes how as movement lessens, in all waters mud and silt are deposited and turbidity may also be affected by water movement and temperature, affecting light penetration. Temperature of the water is he adds, also of vital importance in distribution, metabolism, and life histories of aquatic organisms.

Generation and Water Movement

Langford states that naturally, stream discharge is irregular, though he points out that few rivers remain in their natural state. He identifies the volume and the duration of dry weather flows as critical ecological factors, since flora and fauna have to withstand periods of low flow for hours or months due to variations of precipitation or winter icing. Hydro Electric Power generation from rivers "has marked effects on river flow and current velocities both upstream and downstream from an installation", he states. One of the main effects he notes, is a reduction in current velocity, which results in the deposition of finer materials, mud, silt, and organic solids on normally stony or gravelly riverbeds. Languor states that silt deposits accumulate and so flushing facilities are often incorporated into the dam to remove deposits.

Languor describes how downstream discharge and velocities depend on the pattern of generation, natural river flows, diversion schemes, and the amount of water allowed to by-pass or spill over to maintain a flow in the river, ie 'compensation water.'

Where HEP provides the basic supply, he notes, eg Switzerland, Norway, or Austria, generation continues for 16-24hr, but where HEP is used only for peak demand, generation periods may be only 2-5 hours. In the former case, he states, flows may vary

markedly but regularly, in the latter low flows can last for weeks with considerable ecological impacts.

Langford describes the effect of well planned HEP schemes in general, as suppressing natural extremes and making *annual* flow patterns more uniform. Short term fluctuations may however, he comments, be quite violent with a severe impact on the river's ecology.

Some HEP installations he states, involve diversions of water from a lake or drainage basin to another to enhance flows and this can drastically reduce flows in one and increase flows in another.

Langford notes that although lake water level variations occur naturally, HEP regulation of natural lakes usually increases water level fluctuations, as water is stored in the wet season and drawdown (water consumption) occurs in the dry season.

Sediment and Silt Transport

Sediment and silt transport, Langford states, is affected by hydro electric schemes, principally through bank erosion and rebuilding in rivers, and alluvium deposition in deltas and riverside washes. Upstream of dams, slower currents cause settlement of finer silt and mud, which no longer replenish deltas and alluvial plains. An example Langford cites is the Nile, where flood deposition was so important to crop production that taxes were levied on the height of flood. However, he notes that flushing out sediments accumulated above the dam creates excessive turbidity and silting downstream. Hynes, cited by Langford recommends that flushing practices be discouraged, especially where organic matter has accumulated in sediments.

Thermal Stratification

The complexities of thermal stratification of reservoir water, vertically, due to water density variation with temperature, in lakes is covered fairly thoroughly. Langford considers thermal stratification to be "so profound and so far reaching that it forms [...] the substructure upon which the whole biological framework rests at least in the temperate zone."

Langford then outlines thermal stratification in natural lakes, with the formation of the epilimnion (surface layer), and hypolimnion (bottom stratum). The thermocline he explains, is a stratum usually with temperature decreasing at least 1° C per 0.3 m depth. He states that in some lakes development of stratification may be more complex with one, two or no overturns occurring per annum.

Location of Outlets

Langford states that operation of the turbines influences stratification markedly, depending on the location of turbine inlets. He states that older schemes often have hypolimnion (bottom layer) outlets, while more modern schemes have inlets and outlets at different depths so as to minimise temperature and chemical changes downstream of the dam. Low level hypolimnion outlets, he explains, release colder water, expand the depth of the epilimnion, and lower the thermocline. He notes that releases from multiple levels can avoid affecting the stratification.

The factors affecting temperature of water releases are described. Downstream from dams hypolimnion releases from a reservoir alter the river temperature regime significantly, both

in the short and long term, he states. In summer, temperatures are lowered, and in winter raised, by 1-5 ° C, he states, and the duration of changed temperature depends on the generation regime.

In temperate regions, he states that the effect of hypolimnion releases is to reduce temperature range from 24 ° C to 8 ° C or less depending on dilution. He quotes Banks' conclusion that any river dam would affect the temperature regime downstream, if the impoundment is large and deep enough to stratify. The deeper the impoundment, the greater the changes Langford states, however multi depth outlets have minimised downstream temperature changes. Management of HEP releases can be economically important too, eg Japan where the temperature of the rice paddy fields can be affected, he notes.

Chemical content effects.

Langford states that all lakes cause changes to the chemical balance, which is unique for each river stream or lake .

The chemical conditions with most biological significance are, he states, the levels of oxygen, carbon dioxide and several other gases, calcium, pH, total conductivity, dissolved solids, carbonates, metals, and metal salts and organic matter. The dissolved gases with greatest significance are oxygen, nitrogen, carbon dioxide, and ammonia.

Langford quotes Hawkes, "the concentration of oxygen is the most significant single chemical factor determining the overall selection of species of which the biocoenosis is composed". Nitrogen he states, (originating from the atmosphere), is usually at 100% saturation in natural waters but can be at supersaturated levels in the hypolimnion due to stratification, lack of circulation and hydrostatic pressure, with serious biological consequences in impounded lakes. Langford states that supersaturation leads to bubble gas disease in fish, as has been recorded on the Columbia River. He describes different causes for this, eg by high level discharges over the spill water, or by the passage through turbines with air injection.

Langford states that the effect of HEP operation on chemical content depends largely on where the turbine intakes are set. If they are set low, as with most older dams, then cold de-oxygenated water containing hydrogen sulphide will be discharged, if they are set higher in the epilimnion, warmer oxygenated water will be discharged.

Langford quotes Orlob that the solution to maintaining conditions as near natural as possible, lies in balancing overspill (surface compensation) with turbine outlet water during periods of stratification.

Another significant factor, nutrient levels, depends once again largely on the depth of the discharge intakes, he explains. He states that epilimnion discharges are considered to be nutrient poor, often due to algal blooms while hypolimnion discharges are nutrient rich.

Additionally, if there is pollution in the river, any reduction of the flow will decrease the dilution and exacerbate deleterious effects, Langford notes.

Where HEP schemes involve diversions and water transfers, important chemical effects may ensue, eg by transferring alkaline water into an acid stream, which can alter the character of the water with effects on homing fish and survival of other organisms.

Langford states that "the major physical change *upstream* of a hydro electric dam is the change to a lacustrine habitat from a riverine habitat. The major alterations *downstream* are to the flow and chemistry, and the magnitude of any change depends on the design and operation of the scheme", he states.

Plants

The changes after impoundment of a river are described, eg huge increases in phytoplankton have been recorded, eg on the River Nile. Plant species can change, such as macrophytes -mosses and liverworts changed from river types with rock anchorage, to free floating lacustrine types. Dense mats of floating and rooted plants can become a considerable nuisance, eg in the tropics viz Lake Kariba where it can become a host to pests such as the *Bulnius* snail which transmit schistosomiasis pest infestation.

Fish

Fish are affected by hydro electric schemes through changes to their habitat the author states. Impoundment changes the fish species composition relatively predictably, according to Langford, but increases in total fish numbers are often found in reservoirs. He states that the main concern has been the problems of migratory fish, which migrate between sea and freshwater, in passing dams.

Upstream of dams, the effects of the change in conditions from river to lake are described, causing rheophilic species, adapted to running water, such as grayling, to be replaced by limnophilic species, adapted to slow flowing or standing water. He states that this pattern is repeated all over the world.

He points out that drawdown, -lowering the reservoir water level is particularly adverse in its effects on the littoral (near shore bottom) organisms on which many fish, eg rainbow trout, feed. Some species, he states, spawn on gravel banks in the littoral zones and so are vulnerable to drawdown. He notes that in the larger impounded rivers, HEP uses only a proportion of the flow, but smaller rivers can have no flow or even dry out during non generational periods and fish can suffer due to lack of food or oxygen in stagnant pools.

Fish Migration and Barriers

Langford discusses the subject of obstacles to fish migration from dams and HEP schemes stating that it was realised early on that for the larger dams, by-passes were required. Migratory diadromous species he states, can surmount obstacles up to 1.4m in height and Atlantic salmon can leap up to 3.3m. However, he notes that due to economic pressures, fish passes were often not built, with disastrous consequences for fish. For example Langford states that in Sweden where almost every metre of head was utilised for HEP, migratory fish became almost extinct at one time.

He points out that most HEP schemes have only two or three routes for fish from the reservoir, either via the turbine intakes, the dam spillway, or fish passes if provided. Both turbine intake and spillway can cause injury or mortality, he states. Another effect noted by Langford which impoundment may cause, is serious delay to migration.

Besides the physical barrier, the lack of natural flow variations, quality of water, temperature and the lack of velocity are all cited as possible reasons for disorientation in rheophilic fish. Spates are thought necessary for some fish to migrate upstream, he notes.

Gas bubble disease

Langford writes that gas bubble disease causes fish mortalities on many impounded rivers eg in the USA, and Canada. He states that deep impoundments or turbine tailraces may expose fish to hypolimnion water supersaturated with nitrogen caused by the differential solubility of nitrogen and the other gases in water, at different pressures caused by deep impoundments or turbine tailraces. He notes that balancing surface and hypolimnion discharges or using artificial methods to prevent stratification can generally avoid gas bubble disease.

He states that fish may also become disorientated, by changed currents from HEP schemes.

A comprehensive section on the alleviation of the effects of hydro schemes is included by Langford.

Fish Passages

The various methods are described; fish ladders, lifts, other fishways, road transport. He states that many methods of guiding fish to fishways and away from danger areas have been tried or are used. Screens, air bubble screens, acoustic screens, louvres, travelling screens, and water jets are the main methods employed.

It is noted that though there is an extensive literature reviewing design, construction and operation, their effectiveness has been questioned.

Attracting fish to the entrances of fish passes is a problem, however Langford states that there is little doubt that once a fish enters a fish ladder or lift, it will pass through.

Diversions of water and transfers can create problems of inadequate water flow which are incapable of attracting the migratory fish due to the absence of stimuli.

Beneficial Effects of HEP

The reduction in flooding, and the creation of large new lakes which can be productive fisheries are two benefits Langford mentions, though this will, he states, depend on social and physical circumstances. He cites the Tennessee Valley area as an example, where standing fishery crops of 217kg /ha have been recorded in storage areas and up to 367 kg /ha in mainstream impoundments.

In developed countries he states that huge new areas of aquatic sport have been opened up. In Scotland he notes that lakes created for HEP schemes are used for trout fishing while sailing, swimming, boating, canoeing and water ski-ing are all practiced in reservoirs around the world. The deeper waters of an impoundment are often an aid to water transport too, he notes.

Legal Aspects of HEP ecological impacts

Langford finds little consistency in different countries' approaches to regulation such as minimum compensation flow and fish passage at dams. Although, he states, European law has recognised that dams and weirs obstruct the passage of migratory fish such as salmon and eels, dams were still being constructed without fish passes until the 1970's and even later. He notes that in the UK it was legally established by 1873, that all new dams and weirs should have fish passes with the major legislation on fisheries in the UK, the Salmon

and Freshwater Fisheries Act (1923). He states that in Scotland laws existed from the 17th century regulating obstructions to salmonid migration, and with the major development of HEP schemes considerable R & D effort was applied to fish passage of these obstacles. In other countries, particularly developing ones, the need for electricity was of such overriding importance Langford states, that many schemes were passed which gave cursory consideration to ecological issues. Nowadays, he comments, HEP schemes are no longer so well received in N. America. Langford notes that in Canada considerable opposition to HEP schemes has occurred with hunting and fishing rights of ethnic Indian and Eskimo groups.

Minimum Flow Criteria

The problem of flow alteration which can vary considerably under natural conditions is described. HEP schemes, can however, he states, amplify such variations to the point where the river dries up with resultant serious effects on wildlife and the ecology. Different species have different flow regime requirements. He states that compensation flows are made to keep up the river flow, and he notes that various means for assisting migration in rivers have been suggested. Langford quotes Baxter, who suggested that 20% of the average dry weather flow (A.D.F.) would be necessary to maintain salmonid life-history in a river over a whole year. Wesche is also cited as considering 10% of the annual average discharge (A.A.D.) necessary for short term survival of salmonids in USA streams, and 30% of A.A.D. as satisfactory to maintain a fishery. Langford notes that as the plant becomes older, its operation is changed, from base load to peak-load operation with widely fluctuating use and this can have drastic effects on the river regime and ecology.

He concludes with a section critical of the Environmental Impact Statement (EIS) as a useful tool, first adopted in the USA in 1969. He believes it to be 'grossly wasteful' of research effort. Though the EIS will probably be adopted in Europe, he states it should not be used without criticism and strict controls.

In conclusion Langford asserts that Hydro Electric Power is not 'clean power' in the ecological sense even though there are few additions of contaminants, ...due to "massive and dramatic ecological changes in most rivers of the world", with "extensive chemical changes in rivers". However, "whether any HEP scheme is totally harmful or not depends on the actual situation."

The very high dams proposed such as on the Fraser River in Canada, Langford believes, would need very expensive modification to allow fish passage and conserve fisheries, whereas the lower dams of Scotland, provided that they have fish ladders and multiple level outlets, he believes have probably had less effect on migratory fish than predicted.

The other major work on physical impacts from hydro electric power reviewed here is 'Ecology of Impounded Rivers', by Petts, written at about the same time as Langford's 'Electricity Generation and the Ecology of Natural Waters'.

4. Petts

The *'Ecology of Impounded Rivers. Perspectives for Ecological management'* by Petts (1984), is a comprehensive 326 page book on the effects of dams which covers much of the same topics as Langford, but in greater detail. Petts is an academic and writes from an ecological and environmental perspective. Although the subject matter encompasses electricity generation, damming rivers and not Hydro Electric Power is the subject. Dams are important to all hydro electricity generation since almost all schemes currently employ some form of dam for the purpose of providing a suitable head. Since the energy output varies as a square function of the head, (Twidell & Weir, 1986) any increase in the head results in a large increase in power output. The second main reason for a dam for HEP purposes, is to provide a storage reservoir so that either a steady flow can be maintained through the turbines despite variable feed flow or precipitation, or alternatively so that generation output can be varied in response to fluctuating demand.

In the preface Petts posits some views on why environmental impacts from dammed rivers have only recently become appreciated, even though damming rivers is according to Petts... "without doubt one of the most dramatic, widespread, deliberate impacts of man on the natural environment." Firstly an isolationist attitude in the 1960's by engineers, earth scientists and biologists, secondly, failure until recently to demonstrate the time scale needed before changes could be detected. Thirdly, Petts believes that environmental scientists "have generally failed to communicate their findings convincingly to planners and politicians concerned with the decision making processes".

The book has sections on the biochemical and biological processes, dams, reservoir, geomorphology, bed load, erosion, stratification, ecology.

This book is a mass of detail, heavily buttressed by references and examples. The subject as presented is both very complex and interactive. The approach illustrates the difficulties of describing clear causal linkages from the physical phenomena to the effects on ecosystems and biota, due to the manifold permutations possible in the diversity of environments, and design and operation of reservoirs. The use of diagrammatic models does aid comprehension, though Petts often employs words rather than numbers or graphs, the geographer's approach. The text is often very dense, with themes such as the disruption to natural processes through flow regulation, elimination of most peaks, trapping of the sediment, changes in turbidity (property of an emulsion in diffusing light indirectly), etc, recurring repetitively.

Petts covers the subject under the headings, Reservoir Design & Function, Reservoir Lag, Pulse Releases, Reservoir Life Expectancy and the Quality of Reservoir Releases.

History and extent of Dams

In a section covering the history and extent of dams, Petts states that dams were first introduced 5000 years ago in Egypt, but that the first use of dammed rivers for hydro electric power, did not occur until the late 19th century. During the 1930's, Petts states that series of dams for whole river basin development were first developed for HEP, eg Tennessee Valley USA. Petts quotes White, on the growing unpopularity of dams, saying that by 1977, the great multi purpose dam, which had been a technological symbol was now often attacked as destructive. Petts states that the greatest dam building activity period was between 1945 and 1971, with the peak in 1968.

Growth of environmental impact awareness

Petts quotes Croombe, that by the year 2000, about 60% of the world's total stream flow will be controlled by dams. Before 1960, Petts states, few learned papers were published on impounded rivers, "but there was a big rise in publications in the next two decades, reflecting the sudden realization that deleterious environmental effects can arise from river impoundment". He comments that since the 1950's there has been a tendency to build bigger and bigger dams, resulting in truly man made rivers, that no longer have natural flows and variations in temperature and discharge, with elimination of sediment transport. Petts states that during the 1960's the environmental movement and conservationists questioned the need for large dams and scientists began to discover that irreparable changes could be caused by river impoundment. Physical, chemical and biological impacts of impoundment only received limited attention in 1972, he notes, but the first international conference on the environmental impact of large dams upon the downstream river was held in 1973 in Madrid.

Prior to 1960, Petts points out that the literature was dominated by engineering studies of reservoir sedimentation and channel degradation, related to reservoir safety issues. He notes that over 100 catastrophic dam failures have been recorded for the USA since 1930. During the late 1950's and early 1960's, Petts states, research on the effects of large reservoirs on river water quality and dams as barriers to fish migrations became important themes. He notes that only since the late 1960's have data been available to demonstrate the full ramifications of large dam building on channel morphology, aquatic plants, planktonic and benthic invertebrate communities indigenous fish and riparian, wetland, and floodplain habitats. Petts states that the literature is concerned mainly with the effects of large dams, though they represent less than 5% of the large dams recorded, and the effects of smaller impoundments are less well studied.

Problems arising from river impoundment

Petts lists some of the problems of impoundment as relocation of settlements, transmission of infections, trapping of silt, and fundamental alteration of the water conditions.

An example of relocation of settlements, he cites is on the River Zambezi, Mozambique where 25,000 people were displaced by the reservoir at Cabora Bassa. Petts states that infections can be transmitted by the creation of habitats and new vectors of diseases such as hepatitis, poliomyelitis, typhoid dysentery and cholera, although he concedes that such effects are often due mostly to the irrigation schemes.

Petts emphasises that the particular effects depend on the specific geographic location since dams have been built on rivers in all climatic zones. Significantly, he remarks that the different energy conditions of these zones create some fundamental differences in the water balance, temperature regime and biological processes.

Petts considers the factors determining ecosystems from a fundamental viewpoint. He describes how the ecosystems of river catchments are primarily determined by climate and geology, and that this geomorphological process, is influenced by conditions such as the relief, the run-off rate, ground water, and soil erosion which is in turn controlled by vegetation cover. He notes that vegetation and soil also play a major role in regulating nutrient concentration in stream flow. Petts emphasises the importance of the flood component in a river's ecology.

River Continuum Concept

Petts goes into considerable detail describing the theory of the river continuum concept, a geomorphological process. He states that characteristically, the gradient of the long profile of the river decreases downstream, while the velocity remains relatively unchanged due to increasing efficiency of the channel cross section.

He describes how the different approaches identify characteristic river zones and how the concept assumes smooth continuous adjustments of channel morphology. However, he points out that, the major adjustments which occur at tributary junctions with resulting downstream trends of discharge, drainage area and channel geometry, are step functions. Petts uses this concept of the river's different zones to provide a structure to the processes affected by impounding rivers. The 'gradient of physical factors' formed by the drainage network, "exerts a direct control upon the biological strategies and dynamics of river systems."

The effect of impoundment, Petts states, is generally to cancel out the physical heterogeneity of rivers so that the distinct differences between zones are lost and the diversity is reduced.

Petts acknowledges that many factors are involved in the characteristics of a river and it is difficult to isolate any one factor. However, he proposes that seven primary groups of factors may be identified, or eight including the barrier effect imposed by a dam and reservoir. Three orders of impact he identifies are:

- i) a first order impact occurs from dam closure with the effects of transfer of energy and material into and within the downstream river.
- ii) Second order impacts concern the changes of channel structure and primary production resulting from the first order impacts by local conditions and depend on the characteristics of the river prior to dam closure. These impacts may take between one and one hundred years or more to achieve an 'equilibrium' state according to Petts.
- iii) Third order impacts reflect all the changes of first and second order impacts and the fish population will be affected by changes of the invertebrate community which provides the major food supply for many species. A considerable time lag may be required for these third order effects with several phases of population adjustments taking place. See figure below.

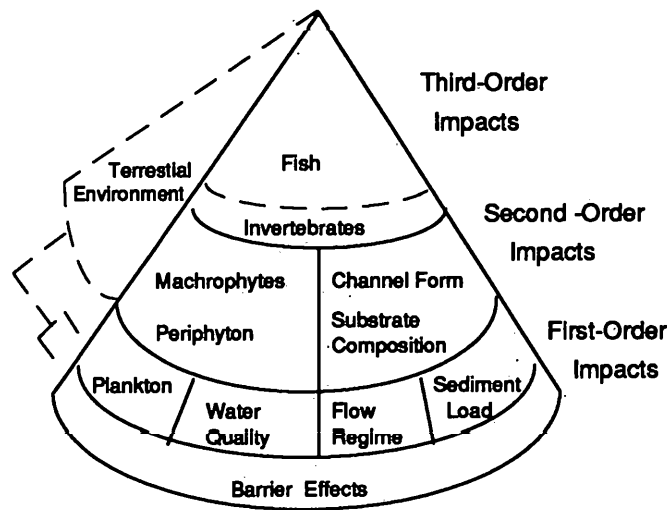


Figure 1. A framework for the examination of impounded rivers from Petts 1984.

Flow and Discharge Rates

Petts describes how the hydrological characteristics of a river exert the fundamental controls on its flowing water systems. He states that the rate of water conveyance, its discharge variability and the frequency of flow extremes over timescales from minutes to months, control physical chemical and biological features of the river. Dam design and operating procedure can produce a range of discharge patterns, he notes, depending on the purpose of the dam. Petts also notes that hydro electric power demands can produce extreme short term flow fluctuations. However, he states that dams are increasingly being operated for multiple purposes and unique flow regimes can result in each impounded river. Other impacts from reservoirs he mentions are increased evaporation, seepage to groundwater, in addition to abstraction of water, all of which can mean a loss of mean discharge.

Petts summarises the effects of flow and discharge rates stating that biological components of flowing water systems are adapted to the flow regime, depending not only on the mean flows but also high flows or periods of low flows, or even zero flow for their life cycles. Periodic high flows can be important for biological systems in a secondary manner eg in cleaning spawning gravels and in their effect on channel shape.

Retention factor and Control of Flooding

Petts describes how impoundment regulates discharge fluctuations and how this is affected by the reservoir size compared to the natural flow variability. He states that the magnitude and timing of floods is normally reduced, eg the 50 years return period flood has been

reduced by over 20%, and the mean annual flood has typically been reduced by more than 25%. Petts describes how multipurpose reservoirs are designed with designated storage volumes allocated for specific purposes. Where the demands are predictable, he states, good management can supply flows with relative ease, -however he comments that, demands change with time and some operational flexibility is required. He explores the theme of alteration or elimination to seasonal flow fluctuations which in many instances exert the dominant controls on ecosystems. Petts gives many examples, such as the Zambezi, where the minimum flow from lake Kariba has increased by 68% in response to increased electricity demand. Another example he provides is the Nile, where after creation of lake Nasser, and loss of 60% of Aswan High Dam releases due to evaporation and irrigation, salt and freshwater flows have been changed in the Mediterranean and salinity in the lower reaches has increased.

He notes that the influence of major flow regulation reservoirs may extend throughout the length of the river, such as reduced freshwater discharges causing salt water incursion into lower reaches, eg Zambezi, Mozambique, and the Dnieper USSR.

Artificial seasonal flow patterns may be imposed. Petts states that in many cases extremely high and low flow years have been eliminated and seasonal fluctuations from eg snow melt run off, have been reversed in some cases.

Pulse Releases

Petts gives examples of hydroelectric power demands producing sudden fluctuations, and pulse releases, eg the Fort Randall dam produces staged fluctuations of up to 2m. He instances very low flows at Glen Canyon Dam which have been observed coinciding with public holidays such as Christmas, New Year's Day, etc, in response to demand. Pulse releases can he states, be very erratic, eg Zambezi, with adverse effects on littoral life,- bottom of river, or lake near the shore.

Quality of Reservoir Releases

Petts describes how water storage in reservoirs alters the physical, chemical and biological character of the water. In natural lakes, common seasonal patterns of physical-chemical changes have been identified. Impoundments show different physical -chemical patterns.

Thermal Stratification

Petts goes into considerable detail explaining the effects of thermal stratification on water quality, water chemistry and the effects on the eco system. He explains how reservoirs with their high mass of relatively still water allow heat storage to occur, while river water he says, usually has a rapid response to ambient temperatures. Petts notes that reservoirs may not develop such a pronounced stratification, since the natural thermal stratification will tend to be interrupted. He states that this will depend on the outflows, and the depth of water outlets. The important factors in stratification are he says, the retention time of stored water, and depth.

Chemical Stratification

Petts describes the main factors as the reservoir water retention time, the dissolved oxygen and solute loading. Other important factors he includes are the flow dynamics and biological activity, especially the phytoplankton in the epilimnion layer where light and higher temperatures occur, and the degree of water mixing and extent of stratification.

Petts states that after building, a reservoir may show considerable oxygen deficiency at depth as submerged terrestrial vegetation decays but this is a temporary phenomenon which will disappear after a few years. However, he states that reservoirs can act as nutrient traps leading to eutrophication, though this is relatively rare in reservoirs due to the large outflows, and short retention times.

Petts like Langford, emphasises the importance of the outflow location in determining the quality of water releases.

Petts states that the pulses of flow fluctuation associated with hydro electric operation can cause short term water quality degradation with sudden changes of water temperature eg 6-8°C below deep release dams. He notes that such sudden river cooling pulses may occur 2-3 times per day.

The topic of supersaturation of gases in water caused by pressure and temperature variations is covered by Petts. Oxygen supersaturation, he states, can also be caused by the turbines of the generating plant, as at low generating levels air has been vented into the system to avoid negative pressures. Other chemical effects of impoundments such as salinity changes eg raised salinity concentrations caused by evaporation and abstraction of water, eg Nile below Aswan dam, and River Murray Basin Australia are discussed.

Mitigation of Stratification

Petts notes that numerous operational techniques and different designs of structures have been employed to prevent stratification, using multiple level draw off points, valve releases, large discharges to generate mixing currents, and selective withdrawal of water from levels.

Petts devotes a section to Seston Transport -very small plankton, stating that impoundment has important effects on turbidity and light penetration and thus photosynthesis and much of the river life. One of the effects of reservoirs on organic matter in a river is to increase the overall organic processing, due to their ability to trap and decompose particulate organic matter.

Sedimentation

According to Petts, "reservoirs will permanently store almost the entire sediment load supplied by the drainage basin." This occurs due to the reduction of velocity of the water flowing into the reservoir, leading to deposition of the load. He states that loss of reservoir storage capacity of over 1% per annum has been observed throughout Europe, and elsewhere, although annual rates are usually less. eg 0.51% in Central Europe. However, he says that large capacity reservoirs or reservoirs draining catchments on rock or well vegetated catchments should only be insignificantly affected by sedimentation eg rates of less than 0.01% per year are common. Determinants of sedimentation that Petts discusses are geology and vegetation cover and reservoir retention time; well vegetated

slopes produce low rates of reservoir storage loss, while high sedimentation rates are usually associated with friable soils, semi arid climates and lack of vegetation cover. Petts notes that reservoir sedimentation was not conceived as a problem until the mid 1920's, but that now many small reservoirs are completely filled with sediment. Dead space, Petts states, may be incorporated into the reservoir design to accommodate sediment and it can be a large proportion of the volume. Petts cites numerous examples of loss of reservoir storage capacity eg. the Heisonghi Reservoir on the Huang Ho river in China which has highest sediment load in world (1.6×10^9 tonnes per year). Once storage capacity has been lost, he states, the reservoir is less capable of attenuating peak floods.

Dam Design and Mitigation of Sedimentation

Dam design now reflects the need to accommodate sedimentation, Petts notes, by provision for dam raising, or providing spare capacity. Eg Lake Nasser and the Aswan High Dam, was provided with 25% spare capacity for silt storage for 500 years. He states that measures to combat sedimentation such as reservoir operations of sluicing and venting can be undertaken. Sluicing he explains, is the opening of large gates near the bottom of the dam, which has the effect of flushing out deposits. Venting is described by Petts as the selective operation of outflow gates at various levels to intercept density currents. He states that while these methods can be effective in reducing sedimentation, they can have a high impact on the downstream ecology.

Channel Morphology

Petts comments that changes to sediment transport have often been considered to be the most important of all the effects of impounding rivers. He notes that the form of channel shape, though continually dynamically changing, does achieve an equilibrium that the river forms by eroding from some locations and depositing in others. This he says, will be modified over some time to reach a new equilibrium and while the 'modification' is in progress higher rates of erosion and sedimentation occur. He states that the timescale for this readjustment may be more than five years to observe any appreciable change, and continuing channel changes may well occur for 50 years, while channel stability may not be achieved for 200 years. Having stated this, Petts also notes that naturally, rivers are seldom in a true state of equilibrium, but continually adjusting through a sequence of scour and fill. He identifies the main factors for excessive erosion rate as: release of silt free water, maintenance of unnatural flow levels, sudden flow-fluctuations, and out of season flooding.

Petts draws attention once again to the adverse effects of power -peaking releases, which, due to repeated sudden water level fluctuations can cause accelerated bank erosion, bank collapses and scouring. He notes that there are sometimes beneficial effects, such as channel deepening for navigation on the Chang River, China, or channel stabilisation. However, he states that in coastal areas, erosional processes are only detrimental. For example he cites deltas eg Rioni River USSR, which are vulnerable, and beaches eg Mozambique which can be affected. Also cited is the trapping of over 100m tons of silt annually at Aswan dam which has prevented beach replenishment within the delta,

allowing coastal erosion of the delta to accelerate, and eliminating the annual silt replenishment of the Nile flood plain.

Vegetation

Petts states that impoundment causes significant changes in plant species, and often increases in algal cover. The type of plant in the river downstream of the dam, he states will be heavily influenced by the type of conditions that result from the dam's design and operation. (The location of outlets and pulse/peaking operation.)

Petts notes that in the tropics floating plants can be a problem where lack of flushing allows infestation often causing deoxygenation, mosquito breeding grounds, eg in Africa.

One of the effects is he mentions, the domination by one species, may be caused by certain conditions and where impoundment leads to a more pulsed flow than before, primary producer communities of aquatic macrophytes and algae can be destroyed or damaged,

Riparian Communities

Naturally, Petts explains rivers have a widely varying flow and floods will inundate low lying land next to the channel, with the channel migrating in this floodplain. Loss of annual silt and nutrient replenishment is considered he states, to be responsible for the gradual loss of fertility of formerly productive floodplain soils. According to Petts, highly seasonal rivers in the tropics show the most sensitivity to hydrological change. He notes that ecosystems may depend on regular flooding, eg Kafue flats in S. Zambia, where a highly productive ecosystem relies on inundation to produce many different conditions for plants and herbivores through successional seasonal vegetational changes.

Petts states that for fauna, floodplains and deltas are of great importance, often serving as breeding grounds. He considers that river impoundment can be disastrous for vegetation, in floodplain habitats where periodic inundation is an essential condition.

Petts quotes Tinley that many dam planners ignore downstream ecology and major releases bear no relation to original flood regimen.

Plankton and Invertebrates / Macroinvertebrates

Plankton are important to aquatic ecosystems, since they are primary biological producers. Reservoirs generally increase plankton populations, Petts says, and cause significant changes in dominant plankton populations from phytoplankton (plant-like) to zooplankton (animal-like) due to alterations of flow, temperature, turbidity and nutrient availability.

Petts notes that research has found that species diversity is usually reduced by river impoundment. He states that impoundment results in monopolization by fewer species with similar effects in plant communities. "Substrate heterogeneity is necessary for maintenance of large number of niches." He adds that while regular variations can be adapted to by flora and fauna, this takes a considerable time period. The combination of severe flow fluctuations and high levels of suspended solids can Petts states, devastate invertebrate populations.

Effect on fish and fisheries.

According to Petts, dams have greater effects on fisheries than any other human activity. One example he cites is that two years after completion of Lake Kainji, River Niger,

Nigeria, fisheries were reduced by 30%. He discusses the effects of impoundment on fish at length covering similar themes to Langford. He states that faunal composition, biomass and diversity are all changed and reduced downstream diversity often results,

Fish Passes and Ladders

Petts also describes the methods used to by pass the dam: fishway construction, fish collection and trucking, and the creation of artificial spawning grounds. Fish ladders he states, usually consist of a long sequence of weirs and pools starting from the tailrace below the dam and climbing in small steps to the reservoir level. However, Petts believes that many fish ladders have been a costly failure where the fish do not negotiate. He cites Bishop & Bell, that fish ladders cannot be justified in high level dams unless reasonable evidence exists that they will prove effective.

Management Problems

Petts concludes that changes in a river are an inevitable result of impoundment. While there is a new awareness of effects, the outcome cannot be precisely predicted, and our knowledge remains incomplete. He discusses the difficulty of determining acceptable change and impacts or hazards especially since as he notes the impacts of dams are highly individualistic. Failure to accept this, he states, and lack of acknowledgement of the size of spatial scales and time periods has led to problems and failures.

According to Petts changes are only predictable in general terms, as the complex interaction of many different factors produces different results. and the varying state of any river under natural conditions. The resilience of a system and its stability are important. Some rivers have high stability but low resilience, others that vary to a great degree might exhibit low stability and high resilience as the organisms / ecological components have become adapted to these varying conditions. Petts quotes Schumm who conceived the existence of thresholds where "while external variables remain relatively constant, the progressive change of the system through time renders it unstable, and failure will occur". Petts identifies four main factors contributing to changes below dams, -the number, kind, severity, (magnitude & frequency) of stress, -stability, resilience, threshold characteristics within natural system, -secondary stresses on biotic component imposed by changes of channel

Petts states that the location of the dam, the maximum desirable flow, minimum flow, optimum flow, rate & frequency of flow variation are of particular importance to HEP operation and discharge fluctuations which if widened can be a very serious impact on river systems. Petts believes that peaking and load following fluctuations can decimate natural river systems with protection almost impossible.

Petts suggests that environmental scientists should seek to anticipate consequences of human impacts over periods as great as 50, 100 or even 500 years. He remarks pertinently that traditionally, "there has been an assumption of high resilience in many of man's efforts to manage his environment, so that no matter how large or permanent the disturbance, the system should retain its original stable condition". However, Petts admits that more than one stable state can be adopted by ecological systems.

He considers mathematical models to be useful to inform decision makers, but that ill defined parameters together with many unjustifiable but necessary assumptions, limit their effectiveness. Rivers, in his view may be viewed as multi faceted systems requiring a multiplicity of models, since "a single model is not a practical objective". Petts states that a fundamental problem for the management of impounded rivers is that the perceived impacts stem from a value scale that appears to be highly weighted and biased towards the benefit of the major water users. "A value system must be established [...] with emphasis on maintenance of ecological and environmental standards within and downstream from water source areas".

Petts considers impoundment to be not necessarily the most desirable alternative, and he advocates leaving some rivers wild as 'gardens of Eden'.

He describes ecological evaluations as moral ones and states that economic evaluations do not include moral or other valuations. Petts makes the point that development of improved responses and approaches to integration with the ecosystem, usually takes the form of control of impacts *after* the dam has been built, rather than anticipatory evaluations.

As may be appreciated from the review above, both Langford and Petts as ecologists focus at a very detailed level on the changes that HEP can result in. This level of detail seems to generate a hyper sensitivity to effects, with perhaps some loss of a robust overview. One criticism of their approach is that it tends to be purist, where any change from the 'natural' can appear detrimental. At the same time, both authors recognise that river systems are continually changing entities and for example, natural changes do themselves produce extinction for specialised species. Langford does acknowledge benefits from impoundments as well as costs. Petts on the other hand, in his search for complete coverage of the subject, appears to adopt a campaigning stance, as a redress for former lack of concern or awareness of impacts. However, Petts' conclusions on the need for ecological value systems, see Chapter 9, are very pertinent as is his point that the timescales for impacts may be enormous.

Design Detail

5. Tesaker

A good example of the design detail necessary for hydro plants so that river functions are maintained is described by Tesaker in a paper '*Hydro Electric Flushing of Sediments at small hydro plants*' (Tesaker, 1986). The author describes some methods of sediment flushing at small hydro plants. He states that transport of sediments in rivers is a well known phenomena. As Petts and Langford have shown above, loads carried by rivers, have important effects and functions for a river. Tesaker states that boulders, gravel and sand may sometimes clog small hydro intakes located in steep rivers, while reservoirs can cause sediments to be deposited. As stated above, this shortens the reservoir life. Floods present the greatest problems, according to Tesaker, and so practical measures are necessary to by-pass sediments. The paper describes three different design models of water intake design by the Norwegian Hydrotechnical Laboratory. These show the great variety of designs possible for flushing sediments, states Tesaker, which will normally be dependent on the scheme's topographical features. Some of the formulae are given for sediment transport, with water velocity being the main factor. The author states that often

to maintain steady flow of the sediments, the channel must be artificially narrowed. He describes the layout of turbine intakes and critical features of the design for sediment by-passes ; turbine intakes are often taken off a channel at the outer bank of a curved section as sediments follow the inner bank due to secondary currents, and the intake cill is placed higher than the bottom.

The second model described is a design with side intake flushing gates in the dam, so that sediments accumulated in the reservoir in a flood can be flushed away. Here, Tesaker states that the cills for the flushing gate are at the base of channel so as to maintain the original river gradient. He notes that sediment entrainment into the intake should be avoided so that damage to the turbines is not caused.

The third model of design described has flushing gates in the dam but a frontal box intake with a submerged flushing tunnel.

Tesaker concludes that the purpose of these model studies is to devise or improve simple low cost arrangements for small hydro intakes. The demand for water for flushing should be minimised, since this is lost to power production. The authors state that when the power demand is equal to the river discharge, about 10-15% of the discharge is needed for flushing for models I and III, and they consider such losses acceptable. When the discharge is 50% higher than powerhouse demand, power production is unaffected. Tesaker states in conclusion that "the difference between a satisfactory and unsatisfactory flushing arrangement, is very often found in small details of the design. Local secondary currents that are important to the flow of bed load sediment may be sensitive to small adjustments."

World Bank Policy and Tradeoffs

6. Goodland

The World Bank, as one of the main financiers of large hydro schemes in developing nations had been criticised on social and environmental grounds.

Goodland, of the World Bank's Office of Environmental Affairs, argues in '*Hydro and the environment: evaluating the tradeoffs*' that identifying tradeoffs between governments and environmentalists at the earliest stage in a hydro power project can reduce "the wastage of human resources, of environmental values, and of material resources"(Goodland, 1986). Writing in the trade journal *Water Power & Dam Construction*, he states that the reservoir at Egypt's Aswan High dam, which started filling in 1964, "alerted the world to the potential for massive environmental costs". Goodland's view is that by 1972-3, "all major environmental aspects were at least acknowledged although not necessarily quantified.." or solutions known. He states that since then, such aspects have been studied and some topics have been so completely absorbed into operating procedure or good engineering practice that they are diminishing as environmental issues". One example which he cites is tectonic activity following reservoir construction.

He goes on to instance four cases of projects involving trade offs, two of which "eventually achieved acceptable tradeoffs: efficiently in Indonesia and with confrontation in Australia", and two that ".. wasted enormous amount of time and resources, although no trade off was reached". The trade offs consist of the setting up of national parks, eg in Indonesia at the Dumoga project, which are intended to protect the watershed, forest, biota, and rare species and also aid resettlement of displaced population. Goodland

believes that "...environmentalists can achieve major gains for the environment which would not be possible without the project", especially where national parks exist on paper only. He cites examples of hydro projects supplying funding to strengthen national parks establishments. However he poses the question of whether environmentalists should admit tradeoffs, stating that many groups feel that to be honourable and effective they should be uncompromising to the bitter end.

On the subject of resettlement, "...which was only taken seriously recently", Goodland states that in 1980, the World Bank adopted the resettlement policy that "...oustees should be no worse off, and preferably better off with the project." The issue of valuable habitat loss is addressed by the new World Bank wildlands policy "...that every wildlife habitat unavoidably lost shall be compensated for by protection of an equivalent tract of similar habitat financed by the project elsewhere." The familiar hydro issues of health effects, water quality, and fish are discussed and the subject of cultural property, ie ancient monuments, is mentioned briefly by Goodland who recommends mitigation or relocation. Mini hydro is, he states, sometimes advantageous "since the environmental impact of water projects is proportional to the surface area of the reservoir, impact can be reduced by decreasing reservoir area." Goodland continues by arguing for the benefits of the controversial Narmada river multi purpose hydro scheme in India. He concludes by linking the themes of energy and national food self-sufficiency, where hydro schemes include irrigation, and states that water projects can become environmentally benign. "Environmental precautions are available, affordable, feasible and tested and their implementation can prevent damage and mitigate environmental costs", he states.

Policy Choices and Bargaining

7. Ayer and Lagassa

An example of the policy choices and bargaining involved in the retro-fitting of hydro schemes to mitigate environmental impacts, is provided by Ayer and Lagassa in an article in *Independent Energy* an industry journal. (F. Ayer, G. Lagassa, 1989). Titled '*Creative Mitigation*', this article describes some of the procedures and manoeuvres involved in licensing for small hydro project refurbishment and enlargement in Maine in North East USA. The authors relate how the company involved had offered to provide mitigation of environmental impacts in order to secure licensing of their scheme. The license is needed to ensure compliance with environmental requirements such as minimum water flow rates. However, the authors relate that the company proposed carrying out mitigation (environmental improvements) on a different river and watershed nearby. By removing an unwanted dam there, salmon access upstream could be restored. The authors recount that the US Fish and Wildlife Service, the regulating body, did not find this acceptable, which then led to a stalemate situation. Ayer and Lagassa describe the attitude of the bureaucracy as "potentially stultifying", in their impact, illustrating the "extreme difficulty of gaining approval for hydroelectric stations in the post Electric Consumers Protection Act era". They relate how a minimum flow rate over the dam, (by-passing the turbines, and so lost to energy production), had been set as a requirement but according to the company this could be eliminated in the revised scheme for only a very slight predicted loss to the salmon habitat. For this reason however, they state, the scheme was turned down. Nevertheless, the authors say, a compromise was reached and construction started,

only for a flood to change the river channel and the habitat. Thereupon the requirements became superfluous, they relate. It was then that the option of environmental mitigation work at the alternative site and river was suggested. The authors state that the Fish and Wildlife Service objected at first on the grounds that each site should be dealt with independently otherwise a precedent would be set. Eventually, they recount, a package of measures including fish passes, and salmon fry stocking was put together, and with an alliance of regional political groups, was influential enough to secure acquiescence of the Federal regulatory body, although the mitigation measures were partly carried out on another river. The authors draw various conclusions, stating that cynically, this might be interpreted as showing how politics gives the ultimate right, or that the rigid insistence on standards by bureaucracies is unreasonable and arrogant, especially when operated from afar. However, their main conclusion is that such approaches are not only creative but can work and will become more common "tools of the trade" in the future.

Impacts and Constraints

8. Moreira and Poole

Moreira and Poole et al cite public resistance to dam construction and hydro electric schemes in a chapter on '*Hydropower and its Constraints*', in the 1160 page book '*Renewable Energy Sources for Fuels and Electricity*', published by Earthscan after the Rio Environmental Summit (Johansson et al 1993). They state that many rivers are now protected against HEP development in Norway, Sweden, and the USA. "Social and environmental concerns have become key factors in determining how much of the remaining hydro potential is in fact viable." They note that impacts and their significance vary greatly from site to site, generalities being heavily conditioned by site specific variations of topography, river flow, climate, ecology, and land use. Some of the unpopularity of hydro power is blamed on poor social and environmental competence in the past. On the subject of the scale of HEP schemes, the authors consider that although some environmental effects are related to scale eg seismicity and construction impacts, "small may be better, but big is not always bad." This is especially so, they state, if the impact per kWh is considered -given the large generating capacity of large high head dams.

The authors discuss the impacts without ranking them in severity, under the headings construction, land use, population resettlement, climatic effects, seismic effects, dam safety, flora and fauna, water quality, sedimentation, aquatic ecosystems, and public health concerns.

Examples are given of construction having a big environmental impact, in S. America, Brazil and other developing areas, where they describe how multiple developments follow the establishment of transport networks with the growth of shanty towns and intense deforestation.

Land Use

Moreira and Poole et al state that land use and inundated areas can vary enormously, as they show in a table. The power / area ratio is described as one rough measure of environmental impact. The Jauari hydroplant of 24MW installed tops the chart at 2400kW per hectare, with the Itaipu plant of 12,600MW at 93.6kW / hectare, while the Balbina

hydroplant has the lowest power to area ratio at 1.1kW / hectare, and the historical average is shown as 21.7kW / hectare. The authors point out that "those schemes with less than 5kW / hectare require more land area than most competing renewable energy technology". They note that inundated land is often fertile and valuable land. The multiple purpose nature of dams and reservoirs is however acknowledged.

However, the point that the function of a reservoir (and the dam to some extent too) is *energy storage* and that HEP plants can be built without reservoirs and large dams, (albeit losing load following capability), is not made.

Other impacts discussed include huge population resettlement, eg the Chinese Three Gorges HEP scheme, where 1.4 million people may be displaced, or the fact that 10% of the cost of a scheme may be devoted to resettlement, eg at Itaparica in Brazil. "In the past such externalities were inadequately accounted for", according to the authors.

Brief mention is made of climatic effects from a large body of water, such as fog or decreased cloud cover in the tropics. These effects are described as roughly in proportion to the surface area. Seismic effects which can occur when filling new reservoirs and after, when settling, as occurred at Vouglans in France, are mentioned. The authors state that dam safety is important since failure can be catastrophic, but large dams tend to be well monitored, it is the smaller dams that are more likely to fail.

On the subject of flora and fauna, the clearing of vegetation before inundation is recommended since submerged rotting vegetation can adversely affect water quality.

The authors point out that "...rivers play a key role in maintaining global ecosystems by circulating fresh water and water borne nutrients", therefore HEP plants can have considerable impact on a river's ecology. While describing the processes of aquatic decomposition and the role of oxygen, they state that oxygen depletion is accentuated in humid tropical regions due to high volume of organic matter, high ambient temperatures and the rapid decomposition. "Fortunately many of these problems are not permanent", they state, since the intensity of eutrophication tends to reflect the ratio of reservoir volume to river flow. Mitigating measures such as clearing of biomass, multilevel water intakes, reparation of deeper level waters and use of aspirating turbines, are suggested.

Sedimentation

The trapping of riverload sediment by dams is described as determined by the watershed, land use patterns, velocity and flow turbulence. The variations in some river loads are shown in a table.

Yellow River	37.6	kg / m ³
Colorado	16.6	"
Armur	2.3	"
Nile	1.6	"
Yangtze	0.4	"
Parana	0.1	"

Table 1. from Johanssen et al 1993.

Methods of mitigation of sedimentation by using base sluice gates and pumping sediments over the dam are mentioned, though it is pointed out that such methods must then be repeated at other dams downstream.

The standard hydro topics of fish migration barriers and turbine damage to fish are covered briefly. Disease and pathogen proliferation such as malaria, schistosomiasis, filariasis and yellow fever are included under public health concerns.

9. Conclusion

Hydro electric power as the literature above describes, has a number of environmental effects many of which impact on the aquatic ecology and also the related terrestrial ecology. Longer term geomorphological effects, concerned with sediment transport exist too, though these appear to require very long time periods to become fully visible. In addition there are effects which impact upon the human domain, eg where potable water is required, or flood control, land occupation by reservoirs, or loss of land at eg deltas.

The literature describes particular impacts from Hydro Electric Power which arise from substantially altering the river flow rate, especially if following demand, or 'peak shaving'. Sudden rapid fluctuations and the creation of no flow periods causing the river to dry out cause particular stress.

The literature reviewed above illustrates a number of different perspectives on environmental impacts of hydro power. Deudney believes hydro to be undervalued as a clean energy source with a large expansion of hydro desirable. Langford and Petts from an ecological perspective are most sceptical of hydro's claim to be clean energy. They describe the important but often unrecognised functions of the river, -ecological and environmental processing.

The paper by Tesaker describes design features to enable one of these river functions - transport of sediment, to continue illustrating that such techniques are available to mitigate impacts and that though they may be crude at present, are capable of being developed further.

Goodland defends World Bank policy on investment in hydro schemes, he understates the environmental effects or considers the problems to be largely solved. When he states that impacts are related to the size of the reservoir, he exhibits a somewhat limited awareness of hydro's effects, confined largely to hydro electric power's effect on the human domain.

Ayer and Lagassa illustrate the convolutions involved in conforming to environmental legislation, together with the 'real world' of ever changing river dynamics.

Moreira and Poole, in Johansson (1993) drawing from a considerable number of sources, and with the advantage writing later, cover both social and physical issues, and include useful data on land use and sediment loading. While they recognise hydro's impacts they put some of the claims into perspective, eg with regard to scale and impact.

Table 2 Summary of Impacts of Hydro Electric Power

<u>High head</u> Dam & Lake	<u>Low head / Run of River</u>
Lacustrine	Only small change
Env. Created	to river gradient.
Land Use	Small/no land use
Incompatibilities	Few/none
Reduced water speed	Smaller reduction of water speed
Wildlife Change	Smaller change in wildlife
Siltation	Smaller silting
Eutrophication	Eutrophication Unlikely
Reduced species diversity ?	" "
Changed Species	Little change
Water table effects	Little/no water table effect
Drainage Effects	Less drainage effects
Flow Changes downstream	" flow change
Increased erosion downstream	"
Water Temp changes	Unlikely
Nutrient loss downstream	Little nutrient loss
Fish migration barrier	Less obstacle to fish mig.
Fish turbine strikes	Can be less
Fish damage from pressure changes	Less
Flood protection	Flood protection (less?)
Flow regulation	Flow regulation (less?)
Often raised levels for navig.	Raised levels for navig.

Chapter 3

Biomass

Introduction

Biomass is energy derived from any organic or plant matter and under this term there is a huge variety of different sources. These include Urban Domestic Wastes, Urban Industrial Wastes, Landfill Gas, Food Processing Wastes, Sewage Wastes, Forestry Wastes, Energy Forestry, Energy Coppicing, Fuel Crops, and Agricultural Wastes.

In terms of resource, biomass is very large, providing about 14% of the world's energy, or 25 million barrels of oil equivalent per day, (=55EJ) according to Hall (1991). He states that it is the most important source in developing countries where it provides about 35%, but it is also important in a number of industrialised countries, eg the US which obtains 4% of its energy from biomass, and Sweden with 14%. Hall points out that photosynthesis produces eight times the current world energy consumption, but states that "the problem is getting the energy to those that need it in an environmentally sustainable manner, which is also economic when all the internal and external costs are accounted for."

While biomass is the most utilised renewable energy source at present, most of its use in developing countries is traditional combustion for cooking, heating and lighting. This review considers only its modern technology use, -much of it for electricity and liquid fuels, high value energy forms.

In the UK, Hall states that biofuel production is currently approximately 1% of primary energy consumption, but that according to the UK Department of Energy, cost effective technologies could allow a potential total of 3% to be produced.

Production

Environmental impacts from biomass for energy can be divided into two parts, firstly production and secondly conversion. This first part mainly reviews the literature covering environmental aspects of production, ie growing the biomass.

Biomass Schemes Assessed

1. Hinkley

Hinkley casts doubt on the 'grand dreams' of biomass energy production on the grounds of land requirement and net energy output as well as other resources, in a paper on large biomass schemes in the USA, titled '*Energy Farms Forests and Fantasies*' (Hinkley, A.D. 1983.) He states that proponents of 'big biomass' argue that R & D on large new biomass schemes is required, not just on the limited resources of waste biomass. He compares four types of biomass energy scheme, energy forest, energy crops, water hyacinth, and marine kelp. He assesses the resource required, versus the net energy gained.

Hinkley describes Inman's (1977) scheme for energy forestry using a fast growing sycamore species coppiced and grown on 50 square miles of land producing 4250×10^9 BTU per annum to power a 50 MW electrical power plant. Fertiliser and herbicide inputs

would be made yearly. The author points out that the energy requirements of such a wood to electricity system are large but states that Inman claims the energy budget is favourable, with an energy output to input ratio of 1 : 10 or more. Inman, he states, acknowledges that diesel pumps for irrigation constitute 40-56% of the energy forest's inputs. However, Hinkley questions the yield, noting that it would take 267 such forests to produce one quad of energy (10^{15} BTU), while the USA's energy consumption at the time was 32 quads, with biomass supplying just 2 quads.

The second scheme considered by Hinkley is for plantations of an energy crop that could be converted into petroleum, citing Calvin (1979) Nielsen et al (1977) and others. A good crop states Hinkley is *Euphorbia Lathyris*, an annual gopher, 8-10% of which constitutes oils; terpenes and isoprenoids. This plan would, states Hinkley, require according to Johnson and Hinman (1980, cit in Hinkley 1983), 46,000 square miles to produce 10% of US oil demand at a rate of 65 barrels per hectare. However, Hinkley casts doubt on the yields pointing out that Johnson and Hinman (1980), admit this would require a 260% increase in yield, and without any irrigation. If the yield were only 13 barrels per hectare, Hinkley estimates that 60 million hectares would be required, equivalent to about the area of Arizona and New Mexico combined. Nor have Nielsen et al included energy costing in their estimates, Hinkley states, and their figures for economic costs are underestimated.

Hinkley briefly considers novel schemes for water hyacinth ponds, "a weed which clogs many waterways in the South Eastern USA and other tropical and sub tropical regions." He states that gross production values are estimated at $32,300 \text{ m}^3 / \text{ha} / \text{yr}$ of biogas methane with an energy content of $1.24 \times 10^6 \text{ MJ} / \text{ha} / \text{year}$. "It would require over 180,000 square miles to produce one quad of gross energy from which energy costs.[...]. should be subtracted to estimate the net energy made available", Hinkley states.

Marine kelp farming for energy is the last of the schemes considered by Hinkley. He states that Wilcox (1976) had envisaged an ocean farming system covering 40,000 ha of ocean to reproduce 16 trillion BTU of synthetic natural gas per year plus many useful by-products. Originally, states Hinkley, the plan was for cultivation in an aquarium with nutrient rich water pumped up from 300m depths, and harvest ships with underwater clippers gathering the kelp. Hinkley relates that three prototype farms were installed, the first was installed about 1000m offshore in California, about 7 acres in size at 100m depth, but without artificial upwelling of deep ocean water. He states that anchorage problems were encountered and the farm was damaged. The second comprising a lattice of wire and rope to which kelp were attached, with waters pumped up, he states, also became damaged in storms, though monitoring continued. Hinkley states that "a kelp farm would have to be very large in order to replace a significant fraction.." of the US's consumption of gas, "30,000 square miles would only supply one quad."

Evaluating these projects, Hinkley's view is that they "are large and tempting targets", which are easy to dismiss, "yet they represent great investments of human ingenuity and ambition". He states that they should be evaluated objectively using rational criteria list as:

- 1) Resources are available for the project
- 2) The project will yield more high quality energy than it consumes.
- 3) There is a demand for the form and quantity of the energy produced
- 4) No significant adverse effects will be caused by the project
- 5) The project will make a significant contribution to the national energy supply

On the subject of resources, Hinkley notes that the kelp farm project needs no land or fertiliser, while water hyacinths obtain nutrients from waste water. However, he adds, the hyacinth ponds, sycamore forests and the euphorbia plantations all require large land areas. Together with this demand for space are water requirements for irrigation and climate tolerance, he states. Another problem he draws attention to is the lack of economies of scale for small wood fired power plant of 50 MW capacity.

Net energy output will be the final judgement on the systems proposed but awaits further trials, according to Hinkley.

Product markets are seen by the author to be needed and in existence before the price can be ascertained. He quotes the energy economics of wood as the most favourable among the biomass options.

The incidence of adverse effects is covered by Hinkley by referring to "moderate to extreme reductions in wildlife diversity", from agricultural, silvicultural, and aquacultural systems, "the release of agricultural chemicals, various degrees of soil compaction and erosion", and also use of marginal lands. Few adverse impacts from water hyacinth production are anticipated by him, apart from phosphate effluents or toxic metal accumulation from waste water. The kelp farms might release carbon dioxide, and possibly create local fogs, as well as changing the wave regime he states.

On the question of significance of the energy contribution, Hinkley quotes some of the supporters of big biomass, and compares these to estimates from some of the sceptics. For example Inman (1977) is quoted as estimating 4.5 quads from 10 million ha of energy forests, in the US while the ERAB (1981) predict 0.13 quads. The OTA (1980b) are quoted as stating the potential of waste water impact on aquaculture is minimal in the US about 0.05 to 0.10 quads per year.

Hinkley concludes that "this is not a tale of ..visionaries'.. dreams destroyed by a hostile establishment, but that none of the technologies has yet crossed the commercialization barrier." He goes on that if large scale biomass production systems are ever to be constructed, they must score well on all five of the evaluation tests. He states that there are at present too many question marks, concerning the technologies, and that full scale "well designed and properly managed field trials are needed", not more paper desk studies.

Concern over the ability of soil resources to sustain biomass energy conversion is a common theme of environmental impact literature, with efforts made to assess the net energy after taking account of energy inputs of fertiliser.

Soil Resources, Limits to Biomass, and Net Energy

2. Pimental

Pimental et al assess the use of agricultural & forestry residues for energy conversion in a paper titled, '*Environmental Risks of Utilising Crop and Forest Residues for Biomass Energy*' (Pimental et al 1983). They make the point that the importance of residues for fertiliser and the environment reduces the potential resource significantly. In their analysis only 20% of the total residues remaining after harvest can be used for energy conversion, being 1.5% of US energy demand. They state that crops and forest residues are a valuable biomass resource for natural, agricultural and forest ecosystems, essential to protect soil

from erosion and rapid water run-off and to maintain soil organic matter and nutrients. In the USA, the authors state, approximately one third of the total biomass produced by photosynthesis is harvested annually, with the residues from crop and forest products totalling 17% of the annual biomass production. These residues are therefore a large resource, say the authors. But they continue, this resource is valuable to soils as nutrients: Phosphates, Potassium, Nitrogen, Calcium and Carbon, and in addition as an organic soil conditioner enhancing water holding and reducing erosion.

Although the crop residues produced annually amount to 410 million tons, quoting Pimental et al (1981) and Shrader (1977), they state that only 15-20% of this can be harvested because of environmental hazards. They state that especially on sloping soils, erosion needs to be controlled by leaving a minimum of two tons per hectare of crop residues on the land to maintain organic matter and soil productivity. Pimental et al state that if crop residues are removed, energy intensive inorganic fertilizers must be applied. They point out that soil organic matter is 58% carbon, and that losing top soil eg 2.5cm from a 30cm soil base will result in a 4% reduction in eg corn yields. Moreover, they state, extra energy needs to be expended to cultivate organically depleted soils.

Forest residues are, say the authors, an essential part of the forest ecosystem, providing a seed bed for seedlings, a source of nutrients, and a protective cover for the top soil. They describe the two types of residues, from firstly logging and secondly from stand improvement or thinnings. They state that an estimated 40% of the 76 million tons of dry matter produced annually from scattered wood, cull trees, upper stems and branches remains after commercial logging. Forest stand improvement produces 43 million dry tons per annum, of which 5% could be used, state the authors, while forest residues vary from 7-20% of the total harvest of 4-100 tons per hectare, though the average residue is 25t / ha.

The authors list four ways in which loss of nutrients from the forest system can occur,

- i) removal of nutrients in bolewood and residues.
- ii) loss of nutrients in eroded forest soil from logging roads and skid trails
- iii) increased leaching of nutrients from forest under greater light and moisture conditions at the forest floor following a harvest.
- iv) additional effects on nutrient cycles including changes in decomposition rates or nitrogen fixing rates having effect on nutrient cycles.

Pimental et al state that whole tree removal results in about double the nutrient loss of bolewood only harvest, with nitrogen and calcium losses greater than Phosphate and Potassium losses. The soil erosion losses of different slope gradients in different parts of the USA are discussed. Good harvesting practice, the authors state, depends mainly on proper road construction and maintenance, since roads and skid trails are responsible for 90% of soil loss from harvesting. Acknowledging that nutrient losses are highly variable, they explain that residues function as dams blocking the sediments, debris and slow water down. The authors trace the inputs of natural nutrients from precipitation through the weathering of parent rock, and nitrogen from biological fixation from the atmosphere. They note that the rate of chemical weathering of the underlying rock material is very variable.

Pimental et al state that energy terms can be used for measuring adverse impacts of removing forestry residues. They relate that studies of energy costs, needed to offset

environmental degradation, were carried out for the North East and the South of the USA. Whole tree harvest of northern hardwoods, required 453 MJ / ha to counter nutrient removal, they report, while whole tree harvest of loblolly pines on a 16 year rotation required 6890 MJ / ha.

The energy cost of collecting logging residues followed by chipping, they state, was calculated at 420 MJ / ton. Where whole tree harvesting is carried out, they state that the energy costs include felling, and bunching and the energy costs are 350MJ / t -760 MJ / t (Pimental 1983). These energy costs are 222 MJ / t if the timber is harvested for forest stand improvements, the authors report. Trucking costs are 190 MJ / ton to transport and deliver chips 70 km one way, state the authors, with the general consensus being that 80 km represents the limit of haul length range. They cite the moisture content of the wood at an estimated 50%, with the energy cost of wood chip haulage at 4.1 MJ / t (wet) / km and 220 MJ / t for loading chips.

Pimental et al also calculate the Net Energy Output from biomass conversion including fertilizer and transport or chipping as well as other conversion losses. For corn (UK maize) and wheat converted into ethanol, and then to electricity, a maximum efficiency of 17%, is reported, but declining to 6% over a 30 year period on a slope of 6-12 % gradient. If electrical energy conversion of crops from such a slope, were used, then the authors calculate there would be a *net energy loss* predicted over a 30 year period.

The maximum net efficiency for conversion to ethanol of forestry residues on low soil erosion slopes was calculated at 17%, for steam only production this was raised to 45% but electricity production brought overall efficiency to down to 11%."All of these conversion efficiencies are quite similar to the conversion efficiencies of corn and wheat residues on land with minimal danger of environmental degradation", state Pimental et al.

They ask the question -"how much liquid fuel, electricity and heat (steam) might be produced from crop and forestry residues harvested from only suitable landsites ?" for the USA. They estimate that the maximum percentages of crop residues that might be utilised, are 18% of the total 400 million tons, 40% of the 76 million tons of forest residues, and 5% of 43 million tons of forest stand improvement wastes or residues. The total of 106 million tons of biomass residues could produce, the authors state, either 834×10^9 MJ of ethanol, 376×10^9 MJ of electricity or $1,166 \times 10^9$ MJ heat (steam) energy gross. This, say Pimental et al, represents, a potential from forest wastes and crop residues of 1.5% of the total USA annual energy consumption, at the time of writing (1981).

The authors conclude that only a small percentage of the residues can be used for biomass energy conversion. The *maximum* production from crop and forestry residues would amount to, they state, about 232 million barrels of high grade liquid fuel, about 6% of US oil consumption at the time, or 5% of electricity production, or 1.5% of total US energy consumption if used as heat (steam). However, the authors emphasise that the *net* yield of energy from residues would be only 10-50% of the gross, due to the large energy inputs from harvesting, hauling, nutrient replacement, and processing. Pimental et al conclude that "both environmental and energy risks of removing crop and forest residues from the land can significantly reduce the net energy return and place major limitations on the availability of these resources." They emphasise that although agricultural and forestry lands cover about 80% of the USA, .."only 20% of the total residues can be utilized for conversion because of environmental limitations and the impracticability of harvesting

some areas of land. Even removing a small portion of the residues in many situations can result in severe soil degradation and water run-off problems". They state that there is a need for the future development of US biomass energy resources, but acknowledge that "with today's agricultural and forest soil management practices, such development would seriously intensify current national problems of soil loss, water run-off and environmental degradation".

The Cost of Soil Erosion from Biomass

3. Pimental & Krummel

Pimental & Krummel, in an academic paper titled *'Biomass Energy and Soil Erosion: Assessment of Resource Costs'*, evaluate soil erosion and energy, fertilizer and costs of biomass for energy in US conditions (Pimental & Krummel, 1987). The extent of soil erosion problems in the USA and the effect of biomass energy production on soil quality is considered. The authors state that soil erosion can occur at the rate of 0-350 Mg per ha per h, with an annual average of 18.1 Mg for cropland. Soil formation rate is, they state only about 1 Mg per ha per year. Pimental & Krummel state that "this erosion rate suggests that US crop soils are being mined at an alarming rate". The importance of organic matter in soils both to nutrient and water retention is then expounded by the authors, mainly for crop cultivation. Slopes, type of crops, methods of cultivation are the relevant factors, state the authors. They then compare this with undisturbed forests, which typically have a very low rate of soil erosion of 0.1 to 0.2 Mg per ha per year, due to the dense soil cover of leaves, twigs, and other organic material. However, the authors state that forest harvesting produces considerable erosion from tracks, vegetation clearance and compaction. Soil formation in forests is also slow they state, at 0.3 Mg per ha per year or 1000 years to produce 2.5 cm of soil. They state that methods of controlling erosion include maintaining vegetation cover which can reduce erosion by a factor of 10-102 and 'no-till' cultivation, which averages one tenth the erosion.

Costs were then allocated to fertiliser nutrients lost in soil erosion losses, in energy terms eg $3.6 \text{ Mg ha}^{-1} \text{ y}^{-1}$, equates to an energy value of 352,000 kcal, they state. Water losses were also translated into energy requirements. Short rotation intensive cultivation fuelwood systems, SRIC, showed a positive energy return but a monetary loss, they report, and perennial herbaceous biomass on flattish slopes, also recorded an energy surplus but an economic loss.

Pimental & Krummel conclude that this accounting system appears to make harvesting corn stover (maize residue), uneconomic, based on yields and soil erosion rates. Perennial herbaceous biomass energy however they state, if properly cultivated, controlled erosion, and although at the time of writing, was unprofitable, future energy price increases could make it profitable. The SRIC produced a net return, economically, though they admit that little data existed.

Sewage Sludge Fertilizer Experiments

4. Hollod

Hollod et al, describe sewage sludge fertiliser experiments that were carried out on pine and hardwood energy plantations in a paper *'The Environmental Effects of Producing Biomass in Pine & Hardwood Plantations for Renewable Energy Resources'* (Hollod et al 1981). They cite the quantity of wood energy resources from all sources, as 3-6 quads, or $3-6 \times 10^9$ BTU, but point out that "if the US is going to exploit the forests for energy and organic resources, then the subsequent effects on the forest ecosystem must be considered." The authors state that the long term objective of the biomass fuels research at the Savannah River Plant is to evaluate the environmental effects of enhancing tree production with sewage sludge. They state that "the fertiliser capacity of sewage sludge could increase forest productivity and save approximately 660 million dollars per year in fertiliser cost". According to one source, they cite, "the energy related expenses of fertiliser production account for 60-70% of the savings." Experimental plots were set up of loblolly pine and soil, and nutrient and water conditions monitored. The authors state that the "presence of heavy metals may be the ultimate constraint for use of sludge in biomass production." Energy and economic costs of applying the sludge will be evaluated and equations for the costs and benefits calculated, say the authors. They anticipate that the nutrient and water retention of the soil will be positively affected. Since long term experiments are required to evaluate the environmental effects, no results are yet available.

Energy Forestry

5. ERL

Environmental Resources Ltd (ERL) carried out a study on environmental issues of energy forestry for ETSU, and Department of Energy, (Environmental Resources Ltd.1988). The authors state that their objectives in the study were i) to identify and assess the effects of energy forestry and their impacts and benefits, ii) to identify the constraints, iii) recommend areas for research and for mitigation, and iv) to provide information on environmental effects to decision makers, land users and others. They state that interest in energy forestry has grown as land is being taken out of agricultural use.

ERL found 2m hectares of land area to be available for energy forestry, though after environmental constraints were introduced this was reduced to 0.9m ha. These constraints were identified they state in broad terms, acknowledging changes in agriculture increase the likelihood of energy forestry on arable or livestock land.

The report describes the environmental effects of energy coppicing, single stem plantations, and modified conventional forestry. A brief description of energy forestry is included; the authors state that the term "refers to the production of wood as a primary source of energy." The environmental effects are considered under the headings of planting and harvesting, impacts, soil and water effects, visual and amenity, and constraints and mitigation. The authors state that planting and harvesting impacts are relatively minor occurring only every 3-6 years for coppices, and every 20 years for single stem plantations, with thinning at year 20 and sporadically at intervals thereafter for modified conventional forestry. Harvesting, say the authors would involve mostly typical forestry equipments such as chippers, forwarders, whole tree harvesters, plus more

specialised coppice harvesters. They state that impacts tend to depend on the quality of the pre-existing vegetation cover and use of the land. Adverse impacts from coppicing, the authors state, would occur on botanically rich land eg neutral grasslands which are increasingly rare and threatened in Britain. However, they note that the use of arable land may actually produce a net benefit in habitats. The intensity of weed control would affect the richness of the habitat, they state, and where scrub woodland was used, the ecology may be adversely affected. The adverse consequences of monocultures are pointed out for coppices in particular, in terms of disease and pest risk, with fire a risk they identify with coppice plantations, especially for eucalypts.

Other impacts the authors identify, concern water use, soil compaction from coppicing and acidification from upland conifer type energy forestry. Sedimentation and erosion of water courses after harvesting might be a problem too for upland forestry, ERL states,

The report considers the effect on the character of the countryside, the landscape, nuisance, access for enjoyment and opportunities.

The authors consider that coppice plantations would probably be located within existing field boundaries in closely spaced rows similar to arable crops except for their size. The authors describe the plantations; small in size, eg 5 hectare and integrated into existing farm units. Foliage and twig colours of willows and poplar are likely to be similar those found in Britain, they state.

ERL concludes that coppice plantations could obscure features in the landscape, if not sited within existing field boundaries. Describing single stem plantations in terms of their visual character, the authors state that they would be fenced with closely spaced trees.

On the subject of constraints, ERL state that coppice plantations should not be planted on or adjacent to archaeological historic sites, National Trust, landscape features or areas outside of the pattern of agricultural land uses, and designated areas such as Areas of Outstanding Natural Beauty and Environmentally Sensitive areas, Heritage Coasts. Single stem plantations should, they state, have the same constraints.

In upland areas, they state that for single stem plantations an adverse impact is likely due to alteration of the traditional landscape, where the small size of plantations could limit landscape possibilities.

Modified conventional forestry is described as differing from conventional forestry in having a slightly more open canopy resulting from thinning operations and greater density of 'rides' or tracks for vehicles. The report describes plantations that would be extensive with mainly coniferous trees providing little rich habitat with broadleaved species used only at the margins for landscape purposes.

ERL states that the areas for planting include blanket bog and moorlands and this would be a significant ecological loss, especially for blanket bogs.

Mitigation measures recommended in the report should include case by case consideration of landscape effects and alternative sites or plantation layout adopted to protect certain features. The need for access for amenity should be taken into account with design the authors state, and also with such operations as harvesting. Liaison with L.A.s over local road use during harvesting is recommended. Measures to avoid acidification, sedimentation and eutrophication should be taken, the report states. Fertilisation should be closely monitored, the authors state, and to maximise habitat potential a mix of species

and different ages should be adopted. They recommend biological control methods, adherence to standard pest control measures and a mix of species to reduce risk of pests.

The ERL Report recommends further research in the areas of:

- developing guidelines for single stem plantation and refining modified conventional forestry.
- Potential benefits of energy forestry for rural economy in light of changes in agricultural policy such as reduction in EC subsidies, set aside and decrease in production.
- Methods of controlling noise and hazards of harvesting machinery.
- Ability of local roads to accommodate traffic associated with harvesting.
- Relationship of root mat development of coppice and its effect on soil compaction, retention of fertilisers and other effects.
- Effects of large scale coppice on planting on wind erosion.
- Effects of single stem forestry especially harvesting, on soil structure, soil nutrients and fertiliser needs.
- Effects of fertilisation in modified conventional forestry, especially on soils high in organic matter.

Based on current predictions, single stem forestry is the least likely to be practiced

According to the authors, coppice planting is more similar to agricultural practice with its frequent cropping, while single stem and modified conventional forestry are versions of forestry practice.

Practitioners of energy forestry are likely to be farmers, they state, or owners of farming land and to have established contacts with organisations responsible for agricultural advice and management. The authors recommend that advice on coppicing should be made available through similar channels to those of agriculture, eg MAF, the National Farming and Wildlife Advisory Group, ADAS and the water authorities, also the Forestry Commission, and Countryside Commission.

ERL concludes that the most important environmental impact from coppicing is the potential use of lowland rough grasslands as these habitats are important botanically and because of the large number of rare protected / threatened bird species they support. ERL suggest a constraint applying here.

They state that many of the other impacts are avoidable through design and siting practices and coppicing could introduce a number of benefits to countryside, soil quality and water resources if converted from arable use, but this will depend on the site in question.

Biomass Energy Status and Potential

6. Hall

Hall provides a general overview of Biomass worldwide including many useful statistics, mainly of the developing world, covering economic, environmental and global warming issues, in a paper titled 'Biomass Energy', (Hall, 1991). Hall sees biomass as providing a key renewable energy resource for sustainable growth, through modernized technologies. He makes the point that biomass sources are extremely diverse, as are the technologies

and fuels derived. This is a problem for planners, he states, who may as a result, ignore biomass. Economic, environmental and energy costs are Hall believes, highly specific to site, species and cultivation practices and cannot be generalized. Hall states that, "the problem of devegetation and deforestation, and its relationship to environmental degradation and global climate change are important components of future biomass energy plans." He states that the use of biomass as a fuel is assumed to be sustainable, but that this is certainly not always the case, and it will be important to know the extent of biomass use and regeneration. "In weighing energy options for the future we will increasingly factor in environmental aspects", he adds. Hall's view is that the evaluation of biomass involves a number of generalizations which, "mainly revolve around the problem that biomass production requires land and time", and that socioeconomic interactions with biomass production can be complex.

Hall reviews several case studies of biomass projects, eucalyptus plantations in Ethiopia, charcoal production in Brazil, bagasse residues in Mauritius, biogas in China, ethanol production in Brazil, woody biomass in the USA, and Sweden and straw in the UK. Some of these he believes are successful and some failures. An example he gives, is charcoal production in Brazil, which although often involving replantation, has also resulted in low yielding neglected forests. The Grande Carajas Programme in Amazonia, if implemented could, he states, "potentially cause serious ecological problems". Industrial demand for charcoal, he states, exceeds sustainable yields and may lead to widespread deforestation and the collapse of the charcoal using industry.

Hall, when discussing environmental issues of biomass energy dwells mainly on the need to produce biomass sustainably and on its role in reducing CO₂ emissions by substituting for fossil fuels and as a CO₂ sink from the atmosphere. "Sequestering the carbon for 20-60 years in the trees would stabilise CO₂ levels in the atmosphere", he states. However, a better and economically more feasible plan would, he believes, be to substitute fossil fuel with sustainably grown biomass using modern energy conversion technologies, such as gasification and turbines to generate electricity, or enzymatic hydrolysis of woody biomass to produce alcohol fuels. Hall states that, "bioenergy strategies have built in economic incentives that make them inherently easier to implement than many alternative strategies for coping with greenhouse warming." He emphasises that the role of existing biomass needs to be understood, and that there are considerable uncertainties in calculating carbon fluxes. Hall voices concern over bio-diversity, and cites experience in Sweden and Ireland where energy coppices have had positive effects. He does however, acknowledge that adverse impacts can be caused by the burning of biomass, eg with open fires, through emission of CO₂, NO_x, CO, CH₄ and other trace gases. "The influence of biomass burning has only been widely recognised over the last few years...such burning may not only pollute the atmosphere and result in increased CO₂...(unless biomass regrows in equilibrium), but may have serious long term effects in soil carbon and erosion..", Hall states. In discussing social issues of biomass for energy, Hall recognises that biomass has multiple uses, not merely energy, and states that the food v fuel argument has been a heatedly debated land use issue.

In conclusion Hall asks "whether biomass is forever ?" His answer is -most certainly, but he admits that whether it will be forever, as a fuel, is debatable. Hall closes optimistically on the themes of the large resource potential, eg a programme of 100 million ha planting

could supply more than 30% of current global electricity demand, modernisation, and environmentally sound technologies, at the same time recognising the many barriers to this renewable source.

Biomass Conversion

Environmental Impacts from renewable energy sources derive from production and secondly from conversion or use of the fuels. Conversion of biomass fuels can be by a variety of means:

- Direct Combustion: domestic grate, stove, industrial furnace, fluid bed.
- Landfill Gas LFG
- Bio Digestion: methane, reactors,
- Pyrolysis
- Chemical Processing
- Fermentation Distillation -alcohol, ethanols, biofuels.

The literature below covers mainly the environmental and technological aspects of the use of biofuels.

The use of Biomass for energy, as has been seen, has its detractors, in both modern and traditional forms. Below is an example of literature critical to a more traditional form which has undeniably the potential to produce substantial pollution.

Pollution from Wood burning

7. Allaby & Lovelock

Wood burning in decentralised small domestic stoves is criticized by Allaby & Lovelock, in an article in New Scientist titled 'Woodstoves the Trendy Pollutant', on several counts (Allaby & Lovelock, 1980). The authors attack, as they see it, the myth of superior environmental performance of woodstoves, as well as the availability and cost of fuel, and the pollutants emitted. Describing the inefficiency of domestic open fire places, they explain the operation of domestic woodstoves, with controlled air flow, to produce slow combustion. This, they state, results unfortunately in the stove behaving "like a wood gasifier or pyroliser", and releasing gases from the wood. These gases are not usually properly re-ignited and burnt but released to the atmosphere, they explain. The emissions they list from wood stoves include such compounds as benzo(a)pyrene, dibenz(a,h)anthracene, benzo(b)fluoranthene, chryzene, and many others, many of which are, they state, carcinogens. Such polycyclic organic emissions are, they state, derived from most incomplete combustion of organic materials, together with the usual, CO and nitrous oxides. In their view, woodstoves are considerably worse polluters than garden bonfires due to such emissions. Centralised combustors burning coal or other (ex)organic matter, can achieve significantly lower emissions performance, they state, and they note that scrubbers are unlikely to be fitted to small decentralised stoves. However, they acknowledge the low sulphur content of wood fuel and hence low SO₂ emissions.

Discussing the demand for fuel, the authors state that "the Forestry Commission in the UK has calculated that the area of coppiced plantation needed to keep the wood burners supplied. A three bedroom house heated entirely by wood-burning stoves, needs three hectares of woodland of which 0.2 ha must be cut and processed each year." They state that this may not sound very much as the UK has 1.25 million ha of forest, but if it is assumed "...that the existing 100,000 stoves or so require 300,000 ha of woodland, this is equal to the entire forest of England..", as most forests are in Scotland. Allaby and Lovelock point out that "despite its renewability, wood, like all biomass fuels can be produced on a large scale only by diverting land from other uses. The authors also raise the spectres of forest depletion in various parts of the world, eg S.America and the USA.

Another issue on which they criticise wood stoves is their impracticability, with regard to the fuel requiring storage and drying space and time. 12 whole months are required to dry the wood they note. Interestingly, they comment that, "the difficulty arises from the relatively low energy density of the wood", pointing out that one ton of coal occupies 0.25m³, while the equivalent wood fuel occupies 4m³.

The authors refer to legislation in the UK, the Clean Air Act, and state that some parts of the NE USA have considerable pollution from stoves. The place for wood stoves is a small one they conclude, -for rural populations with access to sufficient quantities of waste timber, not in densely populated urban areas with sparse afforestation. They believe that "there is a sad irony.." "...that such an embellishment to any home, far from economising on the use of scarce resources while protecting the natural environment, in fact squanders resources and causes environmental damage.."

While Allaby and Lovelock consider decentralised combustors to inevitably have big emissions and poor performance, this need not be the case, as is shown in the literature reviewed below.

Gassification and Combustion

8. Brown

Brown et al discuss design considerations for control technologies to minimize environmental damage in thermochemical conversion of biomass, in a technical paper which assumes familiarity with the subject matter (Brown et al, 1986). This paper evaluates the technology for particulate and tar removal from gas produced by biomass gasifiers and combustion. The authors state that "biomass can be thermochemically converted to fuel gases, electricity or heat by either gasification or combustion technologies." Various types of gasifiers and combustors exist, which have widely varying contaminant loadings, they state. They describe gasification as reacting biomass with hot gases, usually steam, air, and / or oxygen, under reducing conditions to form a combustible fuel or synthesis gas. The authors state that there are three distinct categories: fixed bed, fluid bed and entrained flow and fixed bed types can be either up draft or downdraft. They state that in updraft fixed bed types, 20-25% of the carbon in wood is recovered as liquid products, and the product gas contains little particulate matter. Downdraft fixed bed types, state Brown et al, produce almost no pyrolysis oils, have low tar yields and low particulate loadings, while cross draft types produce some particulates,

mostly ash. The authors state that fluidized bed gasifiers do produce some tars and oils with fairly large but predictable loadings of particulates, described as ash, char and bed material. Entrained flow types have similar loadings they add.

Commenting on the hazards of these emissions, Brown et al state that low temperature oxygenates, (tars), constitute a greater environmental hazard to groundwater, while high temperature tars exhibit carcinogenic properties. All tars and oils are, they state, an operational problem, clogging pipes.

In a following section dealing with biomass combustion, the authors describe the main types of combustors: thin bed spreader stokers, cell type dutch ovens, suspension burners, and fluidized bed. In their opinion, no type is superior, all having advantages and disadvantages. Dutch ovens and underfeed stokers have low particulate emissions, they state, while suspension burners and spreader stokers have higher particulate levels.

Brown et al state that gas cleaning technologies typically remove both particles and tars from gases produced by biomass energy systems. Cyclones, electro-static precipitators, baghouses and other methods are available, they note. Condensation of vapour into droplets of tar may occur, with temperatures being between 150° to 500° C depending on the physical properties of the contaminants, they state. Brown et al comment that tar removal by cyclone, centrifugal separator or wet scrubber lowers the heating value, but may be necessary to avoid clogging and plugging.

The end uses of biomass producer gas are then described, including combustion in kilns, boilers, and oil heaters as well as internal combustion engines, reciprocating or gas turbine. Other applications are mentioned such as a synthesis gas for production of methane, methanol, and liquid hydrocarbon fuels. Brown et al then note some of the requirements for these applications in terms of particulate and tar loadings.

A section then discusses design implementation, where the authors state that two items essential to the design of trouble free gas cleaning systems are 1) particulates and tar should not be removed in the same step, due to the sludge that can result, and 2) when tar removal is necessary, wet scrubbing to condense and remove tars will be required. Tables are included to show technical data.

The authors conclude that "particulate removal technology appears adequate to deal with biomass gas.." though when simultaneous tar removal is required, this may present a problem, requiring further research.

However, the impacts are not necessarily as inevitable as Allaby and Lovelock above suggest. The need for improved residential combustor designs has been recognised in the USA, and elsewhere. As described in the paper below on emissions tests from advanced designs, very significant reductions in emissions and improvements in efficiency can be achieved.

New Technology responses for Wood Burning

9. Burnet

Burnet describes tests on three types of advanced residential combustors, in response to air pollution concern in the Pacific Northwest region of the USA, (Burnet, 1987). He

states in a paper for the Air Pollution Control Association, that in 1982, 1.6 million homes in the region used wood for heating and concern over emissions from woodstoves resulted in emissions regulation being implemented at local, regional and national levels. However, he points out that improved designs do exist, with 40-50 % increases in efficiency over traditional designs, achieved through the use of catalyst equipped stoves, refractory stoves, pellet fuelled stoves and improvements in naturally drafted non catalytic stove designs. Five stoves were tested thoroughly for efficiency and heat output, particulate emission rate, combustion gases, NO_x , SO_2 , volatile organic compounds, polycyclic organic material, bioassay tests for toxicity, acidity and carbon / inorganic content. One stove was of a traditional type, as a baseline control. Generally the stoves were about 75% efficient compared to the traditional type which was about 58% average efficiency, the author states.

Burnet concludes that all the new technology residential devices showed significant reductions in pollutant emissions. The main reductions he states, were of particulate material and carbon monoxide which was reduced by several orders of magnitude, compared to the base line stove, as well as similar reductions in volatile organic compounds. The author states that "...the data show that environmental impacts from wood combustion can be greatly reduced"..., but he notes that particulate samples from all of the stoves were toxic and showed as positive on mutagenicity tests, (ie carcinogenic). While reductions of single pollutants could be made, this did not appear to result in reductions in all the other pollutants, according to Burnet. The lowest pollutant emissions were recorded, the author says, from the pellet stove and the refractory sawdust fuelled stove, though they recorded higher nitric oxides levels, due, he presumes, to their higher operating temperature. He notes however, that these emission rates and concentrations were low compared to automobiles and oil and gas furnaces, and in addition, the acidity of emissions from new stoves are significantly lower than for the baseline stove. Burnet in conclusion remarks that this, "together with lower mass emission rates and lower toxicity from the higher efficiency stoves, may result in lowered overall health impacts from these stove technologies".

Pollution Control Technology

10. ECOTEC

More technical solutions to the problems of biomass energy conversion on a more centralised scale, are provided in *'Review of Pollution Control Technology for Waste Combustion'*, a report for the Government's energy research unit, the Energy Technology Support Unit (ECOTEC, 1990). The purpose of the report is to "provide a technoeconomic assessment of the prospects for energy-from-waste projects in the UK and to advise on R & D requirements". The report makes it plain that development of this 'clean up' technology is driven by the tightening legislation, from the EC and the UK government. The authors state that an extensive review of emissions and pollutants from waste combustion was carried out during the course of the study. A review of the relevant legislation is included.

The wastes considered include domestic refuse, sewage sludge, chemical and toxic waste, medical waste and commercial waste. This detailed technical report contains much useful

description of the chemical processes of pollution such as PCBs, dioxins, as well as the technology of combustion, pollution control techniques and fuel composition.

The main conclusions arrived at in the report are that particulates, hydrogen chloride, heavy metals and trace organics are the main pollutant concerns from waste combustion. The authors state that while there are well established technologies for the control of particulates, hydrogen chloride requires scrubbing in some form, and heavy metals need a combination of these techniques for removal. They note that there are a number of innovative technologies for "simultaneous scrubbing / deNO_x / particulate removal," but that the pace of technological development is dictated by compatibility with fossil fuel markets, and independent waste incineration oriented technology needs to be developed.

However, it might be pointed out that most of these pollutants are not of biomass origin but industrial products, for example plastics and batteries which could be removed by sorting of the waste. The authors do pay some attention to the theme of sorting wastes and removing such hazardous materials, but state that experience eg at the Edmonton energy from waste plant in the UK with sorting and removal has not been encouraging.

On the subject of trace organic pollutants, the authors state that the issue is more complicated and the mechanisms not yet fully understood, especially with regard to the health risks. They mention dioxin pollution and cite the disagreement concerning its importance. Air pollution is, say the authors, not the only issue of concern, as the disposal of bottom and fly ashes, as well as solid and liquid residues from scrubbing systems, is becoming an increasingly important consideration. The report concludes that there is no clear advantage in using any one type of technology, though spray drying techniques are marginally cheaper. The authors state that a number of areas requiring further research can be suggested, for example the behaviour of combustion and scrubber residues in landfills, the feasibility of alternative disposal routes and the study of the formation of the most hazardous pollutants, such as native halogens, chromium IV and submicron particulates. Other areas identified for further research are "the fuel dependence of NO in high nitrogen wastes, (NO_x can be formed thermally from the atmosphere or from the fuel, by oxidation), and air pollution control device reliability".

One of the sources of feedstock biomass for energy is urban and municipal wastes, which need to be disposed of through landfill, materials reclamation or incineration. The energy content is derived largely from paper, card and vegetable matter, all plant produced materials.

Incineration of Municipal Wastes

11. Porteous

Porteous, discusses environmental issues of energy from incineration of wastes, making favourable comparisons with land fill waste disposal, in a paper titled '*Municipal Waste Incineration in the UK -what's holding it back ?*' (Porteous, 1990). He argues for incineration as opposed to landfill, mainly on the grounds of superior economics from energy sales, but also from environmental advantages. These result in his opinion, from reduced methane emissions from landfill, -methane being a potent greenhouse gas, and from displacement of coal. He cites the "lack of enforceable standards" of landfill sites which can often pose hazards to neighbouring landuses. He compares the environmental

effects of incineration, largely the emissions, with those of landfill sites. Porteous states that although "much has been made of emissions from municipal solid wastes (MSW) emissions, the fact is that if operated to new European Community requirements, (as all new and post 1995 incinerators will be), then emissions will match or better those of most UK scheduled combustion installations." He draws attention to the cleaner emissions that can be achieved with flue gas scrubbing, with reductions in HCl, SO₂, HF, particulates, heavy metals, and mercury vapour. Dioxins can he states, be brought down to 0.1 - 2.0 ng / m³, which he considers almost insignificant, comparing them with emissions from bonfires or other uncontrolled incineration.

He argues that landfill sites by comparison, suffer from gas migration, polluted leachate leakage, noxious odours, litter and other hazards. However, in Porteous' view unrealistically low gate charges for waste dumped, have not allowed environmental standards at landfill sites to be raised, and hence landfill appears cheaper than incineration plus energy extraction. The changes from the UK government's Green Bill 1990, and EC legislation will enforce higher standards and the balance will begin to tip in favour of municipal waste incineration plus energy production, he believes.

One omission by Porteous is that many of the more toxic emissions such as dioxins are largely derived from material such as plastics and not biomass materials. The plastics could be removed from the feedstock, resulting in cleaner emissions.

Landfill Gas

Introduction

Landfill Gas (LFG) is methane produced by anaerobic bacterial decomposition of organic wastes at landfill (dumping) sites. This process occurs naturally given the right conditions and most landfill sites generate methane. Since the gas can be hazardous if it migrates or ignites, but it can be exploited as an energy source, the collection and utilization of LFG has been developed for the twin purposes of control of a hazardous by-product and as a renewable energy source. Landfill is the most widely employed means of waste disposal in the UK and a large number of existing sites are available. Adapting sites for landfill gas exploitation is relatively easily accomplished.

12. ETSU

One of a series of six reports on landfill gas titled '*Guidelines for the Safe Control and Utilisation of Landfill Gas*', by ERL for ETSU and The Department of Energy, covers many of the environmental issues of this renewable energy source (ERL, 1993a). The report is aimed at developers, and regulatory & planning bodies, but largely those in the waste disposal industry. Much of the 49 page report is formatted in checklists, in the form of a manual. These reports were produced after the Department of Trade and Industry, and formerly the Department of Energy, had supported an LFG Research & Development programme for some years. The themes covered are Control and Instrumentation, Environmental Impacts and Law, Utilizing Landfill Gas, Gas Wells and Gas Handling and Associated Pipework.

The introduction outlines the origins of landfill, where modern waste management practices lead to anaerobic conditions and a microbial population processes the cellulose to producing LFG as a by product of decay. The hazards of LFG are stated:

- fire, explosion,
- asphyxiation
- toxicity

Methane, the report states, is flammable in concentrations of 5% in air, and when mixed with air it is explosive at concentrations of between 5% and 15%. If such mixtures accumulate and are ignited in confined spaces eg a building, cavity or void, an explosion may result. In the open air a flash fire may result.

The authors state that asphyxiation can be caused by carbon dioxide which is dangerous to human physiology above atmospheric concentrations of 0.04%, with death resulting from prolonged exposure to high concentrations. They state that manholes, sewers, tunnels even poorly ventilated spaces in portable buildings in the vicinity may fill with LFG. Where LFG collects, the report cites the Health and Safety Executive Guidance Note EH40-.... "No one should enter or remain in any confined space where the oxygen content of air has fallen below 18% by volume, as specified.."

The report explains how the anaerobic decomposition process is 'seeded' in part by leachate, which is a combination of rain ingress, moisture from the waste, and the mainly acidic products of cellulose decomposition. This liquid say the authors, acts as a transport medium for the decay process, but can also cause ground and water pollution outside the site.

The report describes how conditions in a landfill tip will change with time so that gas may not be produced initially; the process may in some instances commence only when air ingress ceases, or groundwater rises or leachate recirculates. Gas production therefore can be intermittent, but a typical site will, say the authors, produce LFG for 10-15 years, with smaller intermittent production over 30 years or so.

Landfill Gas Hazards and Risks

The Safety Overview section of Part 1 states that LFG 's major components are methane and carbon dioxide both of which are hazardous, and can present risks to persons and equipment if mishandled. The other constituents, they state are nitrogen, oxygen, carbon dioxide, and small quantities of many trace gases which can include hydrogen sulphide, and give LFG its characteristic odour. The variability of LFG is emphasised by the authors and a full monitoring programme is recommended to ascertain the composition of the gases forming LFG, and how they change during the course of anaerobic decomposition. Some of the other minor gases in LFG such as Hydrogen Sulphide are also toxic when present in sufficient quantities, the authors state.

Other hazards of Landfill Gas the report describes as mainly those associated with any landfill tips. They are listed as - trips and falls, plant and vehicle movement, electrical hazards, cuts and abrasions, infectious disease, excavations and unstable ground.

and also the toxicity of liquid leachate and condensate, which can contain hazardous chemical elements, eg arsenic.

Site Operations

The authors state that the operations should involve the containment of LFG within the site limits, the control of gas pressure within the landfill mass, and the controlled relief of such pressure in a safe and environmentally acceptable manner", being discharged, incinerated, flared or used.

Part of the section on Quality Assurance includes a list of examples of potential risks:

Action	Potential Effect	Potential Risk
Landfill Operations	Site Lining failure, leachate migration.	Surface water & Groundwater Contamination
	Incorrect wastes types	As above, Reaction
	Litter	Cattle Choking Uncovered wastes encouraging birds. Aircraft bird strike
	Hazardous Conditions	Injury to workers, visitors, trespassers, etc.
Landfill Gas Management	Gas 'escape' or migration	Fire, explosion, asphyxiation, Plant or crop damage. 'Blighting' of land.
Exploitation of gas	Process equipment failure	Gas migration or leakage Failure to supply customers. Consequential loss.
	Flare	Navigational distraction hazard.
General	Settlement of landfill (gross and differential).	Building structural damage. Damage to foundations. Damage to gas collection equipment.

Table 3. Examples of Potential Risks of Landfill Gas from ERL 1993a.

The authors state that these risks of LFG production can be evaluated and need to be controlled by good design, physical protection, supervision and alternative methods.

The introduction of Part 3 of *'Guidelines for the Safe Control and Utilisation of Landfill Gas'*, sets out the aim as "to ensure that any scheme which sets out to control actively or utilise LFG, does so in a safe and effective manner". The authors state that there will be an effect on the environment whenever LFG is produced, and reiterate the hazards noted above, but add damage to surface vegetation.

The authors point out that the gas management system controlling LFG, can create other impacts on the environment, such as visual intrusion, land-take, noise, and secondary

emissions. The increasing stringency of the landfill site regulations eg the Environmental Protection Act 1990 is noted. Legal considerations are covered by listing the regulatory bodies, noting recent changes. The topics of Legal Liability, Planning Consent and Site Licence are covered.

The report states that the construction of buildings or other operations for the use of land for retaining, treating or disposing of trade waste are 'bad neighbour' developments which must be publicly advertised as part of the process of applying for planning permission.

Environmental Assessment is required the report notes, for major projects of more than 75,000 tons a year of household, industrial and commercial wastes or projects in particularly sensitive and vulnerable locations.

Site features are described in the report as having adequate quantities of degradable waste available for the landfill to produce LFG, above 100,000 tons typically. Also included is the lining -depending on the geology or a series of membranes which can resist infill and decomposition products. The authors note that clays or synthetic materials have been employed. They state that groundwater should be prevented from entering the landfill, for although the site requires some water for microbial action, an excess, or leachate, can lead to groundwater pollution. They acknowledge that some leachate is inevitable and must be managed.

Another requirement that they include is a cap, so that odour can be contained, gas can be collected and temporary vents, ditches and chimneys may be employed to disperse the odours, or gases may be flared and even deodorants used to mask odours.

The stages of landfill operation, Site Preparation, Infill, Gas Collection, Gas Exploitation, and Aftercare are then dealt with in turn considering associated impacts.

The Infill phase, the report states, requires mobile compaction vehicles to encourage anaerobic decomposition. As this takes place, according to the report, the leachate level rises, either reabsorbed or running off requiring management. Fresh leachate has a high Biological Oxygen Demand (BOD), and the potential to pollute, say the authors, but eventually becomes 'spent' with a low BOD, and COD (Chemical Oxygen Demand) but with a high ammonia and nitrogen content and some leachate will need to be treated, eg to remove ammonia.

The principle environmental impacts from the Gas Exploitation Phase are listed by the authors as visual from gas well heads, pipes, and extraction equipment and flares. noise from extraction pumps, water removal equipment electricity generators, and the flare. Emissions, they state, derive from condensate from the water removal process and flare combustion products.

Catastrophic instances of LFG emerging at remote locations and causing loss of life, injury or property damage, have occurred they note.

The report states that controlled landfill can be used to reclaim derelict land eg after mineral extraction but recommends that no housing is built on landfills that are producing gas or have the potential to and housing development on landfill sites. The principal difficulties of building on or near landfill are described as gross settlement, differential settlement, gas production, leachate, and utility service difficulties.

Clearly there are a large number of environmental impacts from LFG, or rather from landfilling. Landfilling as a means of refuse disposal is expected to decline in the future due

to tighter regulations, and though LFG gas can help reduce hazards and produce some energy, this is very much a secondary concern. Incineration generates much more energy per mass, and digestion in landfill is far less efficient than biodigestion in a reactor in controlled conditions. As Porteous stated earlier, there is considerable difficulty in enforcing tighter standards.

Conclusion

The literature reviewed above demonstrates that Biomass Energy can have significant impacts from soil and water resource depletion, and from over production. Species diversity can also be reduced by biomass for energy plantations replacing formerly varied plant populations, although this will depend on what vegetation is being replaced. The degree of impact from biomass production is very site specific depending on the soil and water resources, production levels and the climate. The scale of biomass collection can pose an impact eg in transport terms, in itself since the fuel does not have a high energy density. This low energy density results in fairly large land use per unit of energy. The second stage of impacts are from conversion and their extent depends to a large degree on the type of technology employed. Traditional conversion technology especially combustion, tends to be inefficient, and can lead to significant emission of pollutants. Such emissions are more equivalent to those from fossil fuels, though often slightly less noxious. More modern technology however, can achieve very much cleaner conversion performance.

Despite the emission of some pollutants, there can be significant positive effects from the use of biomass for energy where biomass wastes, the disposal of which is a problem, form the fuel feedstock.

Table 4 Summary Showing Impacts from Biomass.

<u>Production</u>	<u>Conversion</u>
Visual	Visual
	Noise
	Safety
Wildlife+	
Soil Effects	
Water Req	
Fertilizer	
Land-use	Land-use
	Planning Incompatibilities
	Emissions: gas, liquid, solid

Chapter 4

Geothermal

Introduction

Geothermal Energy is, after hydro power and biomass, the third most exploited renewable energy source with 6000 MW of installed generation capacity in 21 different countries. Geothermal energy abstracts heat from the earth's crust from either pre existing aquifer, or injected water flow in the case of Hot Dry Rock technology. The latter is still in the very early stages of development and is not yet commercially exploited and so this chapter only covers Aquifer Geothermal Energy. The exploitation of aquifer geothermal energy is about 100 years old, excluding the traditional use of hot springs (Garnish 1984).

Energy conversion can be either via mechanical means or the heat can be used directly. Geothermal energy is in one sense only partially renewable, since the reservoir of heat that is being tapped into is not usually replenished at the rate that energy is extracted. (Garnish 1984). However, it does represent a natural energy flow.

Hot aquifers are found in many areas usually associated with the volcanic activity found near tectonic plate boundaries. The mean earth surface value for Geothermal heat emission is only $0.01\text{-}0.05\text{Wm}^{-2}$, (Richardson 1979), but there are very great variations in the energy flux, eg the Geysers.

1. Technology

Steam or hot water under pressure, derived by a borehole from underground aquifers (water bearing strata) is used to drive turbines or heat engines which drive generators. The plant required to do this comprises in principle, the production wells from which steam is collected and transmitted by pipelines to a turbine. In practice, other plant is required as well; cyclone separators to remove particulate matter, drain pots along the pipes to remove condensate, and moisture separators before the turbines (DiPippo 1991). There are also several variants of the technology to suit the particular conditions of different aquifers.

Depending on the temperature and pressure of the aquifer, the fluid may emerge as either dry steam or hot water under pressure that must be flashed to steam. Hypersaline brines, or steam with high levels of non condensable gases may be utilised requiring special plant.

Because of the high temperatures and pressures involved, geothermal fluids normally carry a wide assortment of dissolved minerals from the many chemical reactions that may take place with rocks. The dissolved solids in most geothermal fluids are not a big problem for use in generation plant with the availability of relatively simple and inexpensive means of controlling scaling or corrosion problems (DiPippo 1991). High temperature fluids though, eg 300°C with 200,000-300,000 ppm dissolved solids as found at the Salton Sea reservoir ranges, need crystallizers and then disposal of solids, which is a source of environmental impact. (DiPippo 1991.) Garnish, in a paper concerned mainly with the lower temperature reservoirs, cites the great age of the deeper geothermal fluids, eg 15 million years old at the Marchwood geothermal borehole near Southampton (Price 1982) as the contributing factor to the number of dissolved chemicals.

Earlier technology released geothermal fluids to rivers, but nowadays reinjection is often required. Binary plants which have an independent working fluid circuit driving a heat engine, are used where scaling, corrosion or non condensable gases occur in the fluid. Binary plants can be particularly suitable for the lower temperature geothermal fluids, eg in the range 120-150°C and with pumped reinjection have lower environmental impacts. Gases are usually vented to the atmosphere, and the impact will depend on the composition, the concentration and quantity.

While DiPippo, appears to play down the environmental impacts from geothermal energy, Garnish stated in 1984 (Garnish 1984), that most geothermal energy exploitation had occurred in remote locations in volcanically active areas, with little attention paid to environmental consequences. He considers that "with more care the environmental consequences of development in these areas should be negligible."

DiPippo (1991) states that there is a considerable literature on the environmental impacts of geothermal energy, and that the main impacts are air pollution, water pollution, noise pollution, land use, water use, thermal pollution, land subsidence, destruction of natural wonders, aesthetics, and catastrophic events. Only the first four are, he considers significant enough to be discussed in detail.

The emission points for pollutants are he states, dependent on the type of plant but are commonly the silencers at the wellheads and power houses, the drains and traps from geothermal pipelines, vents from non condensable gas injectors, and blow down of excess condensate from the cooling tower. Other points that DiPippo considers may be important for emission releases, are condenser cooling water outlet, brine discharges, if not reinjected, geofluid exhaust from the turbine (for a discharge to atmosphere unit), and outlet streams for gas abatement.

2. Air Pollution

DiPippo, states that non condensable gases such as carbon dioxide (CO₂) and hydrogen sulphide (H₂S) and very small amounts of methane, hydrogen and ammonia vented to the air may cause air pollution. H₂S is, says DiPippo, considered a problem since it is harmful in small quantities and its odour detectable at only 30 parts per billion. He notes that the USA has strict regulations governing its release, however, CO₂ emission, although an important greenhouse gas is not yet regulated, and is "a cause for concern". However, he compares the CO₂ emissions favourably with those of other CO₂ emitting plant, eg only 5% that of coal and 8% that of oil per kWh. In sparsely populated areas H₂S emissions are not usually seen as a problem, he states, especially since in geothermal areas the air is likely to already be burdened with natural emissions from fumaroles, hot springs, mud pots etc.

A paper by Altshuler et al (Altshuler 1984) on air pollutants at the Geysers Geothermal Plants, describes measurements of concentrations of mercury vapour, ammonia, radon, respirable suspended particles, boron particulates, benzene, total suspended particles, sulphates and hydrogen sulphide. Only hydrogen sulphide concentrations exceeded the air quality limits, and only by a small margin, with only a small number of incidents in populated areas. Although no limits existed at the time for mercury, arsenic, vanadium,

benzene, ammonia, boron, silicon, and radon, concentrations all of them were found to be at or near to detectable limits. The authors do however, caution that the concentrations of mercury vapour need to be monitored since there had been a significant rise in mercury vapour between 1972 and 1982. The rise in mercury vapour emissions may however, they state, be due to geological cinnabar deposits or past mining operations rather than geothermal steam utilization.

The difficulty of predicting and assessing geothermal air pollution is illustrated in another paper dealing with air pollution impacts by Tesche et al. (Tesche, 1985). This paper deals with modelling the hydrogen sulphide concentrations and dispersal rates in the Geysers area. Since there are a number of emission sources, and weather conditions are significant in dispersal, modelling is complicated and has to be based on a matrix system. Emissions from geothermal energy utilization must be superimposed on natural emissions from the Geysers hot springs further complicating the exercise.

Economides and Ungemach state that H_2S releases to the atmosphere generate SO_2 and this has long been noticed at the geothermal station at Larderello in N. Italy to cause acid rain resulting in corrosion to plant equipment. (Economides & Ungemach, 1987)

DiPippo states that technology for H_2S abatement, such as the Stretford system which achieves 90% plus reduction, is available in the USA. (DiPippo 1991). However, he notes that binary plants, which employ two separate closed fluid cycles have no gaseous emissions.

3. Water Pollution

It is the high temperature reservoirs of above 230° C that contain dissolved minerals such as Cl, Na, K, Ca, B, Li, As, F, Mg, Si, I, Rb, Sb, Sr, bicarbonate and sulphate (DiPippo 1991). Though not all would be present in significant quantities at all sites, some could seriously affect surface waters depending on their concentration. Lower temperature reservoirs often yield relatively clean fluids with less than 1000 ppm of total dissolved solids (DiPippo 1991). One way in which ground water may be contaminated is if the casings in reinjection wells fail, which may allow the fluid to pass into shallow aquifers. DiPippo says that this can be eliminated by careful design, attention to quality control, during drilling and construction and monitoring during operation.

Garnish (1984) states that problems may arise below ground, for example the contamination of potable water in shallow aquifers by the geothermal chemically laden brine. Special casings for the borehole may be required to resist corrosion eg a nitrogen blanket in the borehole to prevent oxygen ingress and thus corrosion of steel tubing, depending on the chemical nature of the fluid. With careful design, Garnish considers the risks of below ground environmental impact to be small.

Garnish states that no rivers in the UK could accept the load of brines which may be 25% or more dissolved solids, mainly chlorides, sulphates and carbonates.

Although surface disposal is common outside of the USA and Japan, he states, there is now a trend to reinjection eg new plant in New Zealand, Costa Rica and El Salvador.

Garnish states that in low enthalpy reservoirs, ie those with lower temperatures, the major dissolved constituent is often sodium chloride, which may be in concentrations as high as 30%. He points out that together with the other dissolved compounds, this fluid is highly

corrosive and heat exchangers with stainless and titanium plates need to be used. As rejection to the surface is rarely practicable, reinjection is necessary. This also serves to prevent reservoir fluid loss which can cause a drop in pressure and so subsidence (Garnish 1984). Reservoir life is also extended with reinjection, 25 years being about the maximum expected. Reinjection does however, usually require a second borehole and pumps which constitute a parasitic energy demand.

4. Seismicity

Induced seismicity DiPippo (1991) states, is caused by injection of high pressure liquid moving fractured and stressed rocks. Reinjection of waste brines is similar but DiPippo considers that the pressures are not sufficient to cause problems. Studies have, he says shown that injection or production of geothermal fluids does not produce earthquakes but at the most causes microseismic events.

Borsetto et al in a paper on environmental effects of fluid reinjection into geothermal reservoirs, (Borsetto et al, 1983) consider the effects on the reservoir field of reinjection. Their paper is a technical one in the field of 'reservoir engineering', and concerns numerical methods of heat transfer. The authors state that while it was known that massive injection programmes could trigger seismic events, ('Continued Seismic Monitoring of the Geysers Geothermal area, California', R. S. Ludwin, C.G.Bufe, 1980, Open File Report Number 80, US. Geological Survey, Menlo Park California, 1980. cit in Borsetto et al 1983), the injection of cool water of about 30-60° C into hot formations of 200-300° C causes important additional effects to those of pressure. They describe how thermal effects caused by the cold fluid front moving through the reservoir, are linked to pressure and rock stresses and can cause rocks to fracture. The release of this energy, they state, as well as thermal contraction can cause micro seismic events or subsidence. The authors note that modelling the effects of reinjection has been important for ensuring maximum reservoir life and minimising the potential for subsidence and seismic events.

5. Noise Pollution

The cause of the greatest noise is well drilling, DiPippo states. Normal operation does not generate objectionable noise, he states, though for brief periods, in emergency conditions the venting of steam may give rise to high noise levels for short periods. Rock mufflers are usually employed to reduce noise, he states. He cites experience at the Geysers geothermal plant California USA, which has shown very high noise levels of 114db(A) from geothermal air drilling rig with 23 kg/s steam entry and no muffler when measured at 8m distance. With a muffler this drops to 84db(A), states DiPippo (1991), and at 75m it is 65db(A). Other sources he quotes are water cooling towers (82-83 db(A) at 3m distance), and an open geothermal steam well discharging vertically, the noisiest occurrence is 71-83 db(A) at 900m. No figure is given for this event close up! The turbine building is quoted as emitting 73db(A) at 8m.

DiPippo's comment is that even with the wide open vertically discharging well, "one of the worst possible noise sources..", at 1km the sound is no worse than a typically noisy urban

area, and that the routine noises of plant operation are practically indistinguishable from other background noises.

Garnish (1984) considers impacts associated with drilling and establishing the borehole to be temporary, eg only 30-40 days taken to drill a single well. He states that silenced drilling is available and cites the round the clock drilling in 1981 of the geothermal borehole at Southampton which although it was within 300m of the nearest habitation, received no complaints. Care should also be taken to replace the topsoil after the drilling operation he says. Surface equipment for heat only installations may be confined to pipework valves and a control building.

6. Land Use

Geothermal plants in common with most renewables are site specific, in that as long pipelines are impracticable, they must be sited on the geothermal field. The power house, the cooling towers, the electrical connections, the well pads and the pipelines all require land. While the well field can cover a large area, the land around can still be used for farming. For the 180MW Cerro Prieto I plant in Mexico, the total area encompassed by all the wells comes to $5.4 \times 10^6 \text{ m}^2$ or 540ha. (EPRI 1987)) Of this area only 2% is actually occupied by the well pads. DiPippo states that geothermal plants require less land per MW than competing power plants, with $1200\text{m}^2 / \text{MW}$ for geothermal single flash plant, or $2700\text{m}^2 / \text{MW}$ for a binary plant. By comparison he cites nuclear at $10,000\text{m}^2 / \text{MW}$, solar thermal at $28,000\text{m}^2 / \text{MW}$, coal / steam at $40,000\text{m}^2 / \text{MW}$, and solar photovoltaic at $66,000\text{m}^2 / \text{MW}$.

7. Other Impacts

DiPippo points out that geothermal plants vent large amounts of heat since they operate at low thermodynamic efficiency. For example in a table he shows that geothermal plants reject 9 units of heat per unit of power output as compared with coal-steam plants which reject 1.7 units. Water consumption for cooling purposes is not generally a problem since it is either supplied in the form of the geothermal fluid or air cooling is used for binary plant.

Borsetto et al, however, state that the effect of thermal energy discharges, which they state is about 5 times that for conventional power stations, ... "may modify the local climate and favour the formation of fog". (Borsetto et al 1986).

Subsidence

Subsidence has only been a problem at the Wairakei field in New Zealand, according to DiPippo, where the maximum drop in ground level exceeds 7.5m and is continuing at an annual rate of 0.4m (GRCT 1990). This he says is confined to a small area away from the powerhouse and has not caused major difficulties. Garnish considers possible environmental effects from changes in surface temperatures from thermal extraction. But since the background average heat emission value (given above) is so low, changes in it, - even to zero, would, he considers, have an imperceptible effect. He states that cooling a mass of rock by eg 50°C will result "in a volumetric reduction of some 0.2% which may well be sufficient to cause some fracturing of the rock matrix". However, unless the

stresses of rocks in the region are already high, the effects will be too small to be detectable at the surface. A maximum reduction of 25mm might occur if the reservoir were 50m thick, but relaxation of surface strata would make this imperceptible at the surface (Garnish 1984).

Water extraction can create problems, eg a low enthalpy reservoir may extract 80-150m³ of water per day (Olivet & Deslandes, 1978). Over a long period this can cause subsidence but Garnish states, this applies mainly to shallower high enthalpy reservoirs where the mechanical strength of the volcanic rocks is low.

The possibility of the destruction of natural wonders, eg geysers or hot springs can be countered by taking care to preserve them wherever they are tourist attractions, DiPippo states. "Such areas are normally specially designated as national parks and are off limits to development eg USA, Japan, Costa Rica."

8. Protection Policy Development in Hawaii

Hannah, of the University of Hawaii describes the process of protection policy development for wildlife and nature conservation in Hawaii where there have been considerable geothermal energy developments as well as a concentration of rare, endangered species *'Protection Policy for Hawaii's Native Wildlife during Geothermal Energy Development'* (Hannah, 1986). The importance of sound choice of assessment methodology is illustrated.

Geothermal energy developments have existed since about 1960 but had not initially been located in land of environmental significance and posed little threat to native flora and fauna. Hawaii started a significant renewable energy development policy and by 1981 larger scale geothermal development was nearing the licensing stage. Hawaii also has the greatest concentration of endangered species of any US state (Hannah 1986). Over 40% of native bird species are endangered, as is the only native terrestrial mammal and there are more endangered bird species than in the whole N.American continent. This makes nature conservation critically important on the islands. There are indeed protected zones and a Hawaii Volcanoes National Park is designated. However, the lack of experience with geothermal energy in the regulatory area, Hannah states, tested the efficacy of existing regulation and led to uncertainty on the part of developers and protection organisations. Both Federal and State law required environmental impact statements, (EIS) but these operated primarily to inform the public rather than to enforce protection. The US Fish and Wildlife Service did not interpret habitat modification as 'harm' under the Endangered Species Act, and so these laws imposed few constraints on geothermal development especially on private land.

Hawaiian land use law, however, could be used to protect wildlife in sensitive areas. After a public controversy caused by approval of geothermal exploration in a conservation district, the land use law was superseded for geothermal development by the Geothermal Subzone Act which essentially designated areas as potential geothermal zones. These zones would be exempt from normal environmental impact assessment, but would be assessed on both geothermal and environmental and social impacts in terms of a balance of interests. Hannah states that this was seen by conservation interests, as a flawed process

with excessive weighting given to developers. The designations themselves included some environmentally valuable and sensitive areas, eg the Kilauea Island East Rift, (Hannah 1986). In the process a best balance equal weighting was supposed to be achieved, but did not appear to select the areas of lowest impacts / highest economic and social gains, and were highly controversial according to Hannah. Environmental and community groups appealed against the designations. They were however upheld, though a 'trade' of sensitive and non sensitive areas was proposed. This says Hannah could avert major detriment to native wildlife some of which is critically endangered. Hannah concludes that existing environmental and land use laws have been shown to offer little protection to important wildlife resources. An inappropriate and flawed assessment methodology has created a precedent for exploration and development in vulnerable and valuable areas. However, "sound assessment methodology could restore the Geothermal Subzone Act as a tool for proper constraint of geothermal energy." Creative approaches such as the trade in zones are, he states, the best solution to land use conflicts, but they need to originate from state initiatives rather than from public pressure.

9. Public Attitudes in Hawaii

Another paper from a member of the University of Hawaii, by Johnson describes the results of a survey of public attitudes, '*Geothermal Hawaiian Attitudes toward Geothermal Development*' (Johnson 1982). A grass roots community organisation was contacted by native Hawaiians concerned at the activities of land speculators and several oil companies interested in geothermal developments. They were also concerned with ownership of the geothermal resource, traditional Hawaiian beliefs and use of the land. 255 households responded to the survey, an 85% response rate. Questions asked concerned attitudes towards geothermal development, lifestyle, cultural practices and values of the Hawaiian Community. The extent and sources of respondents information was investigated. Respondents were also asked to indicate both the *value* and the *magnitude* of perceived effects of development. A group of 15 Hawaiian community leaders were taken on a visit to the New Zealand geothermal fields, and their attitudes were assessed too.

About 25% of the sample considered they had a small amount of information about geothermal energy, and 30% had either no or very small amount of information. While the economic impacts were perceived as being 'good', all the other impacts were placed in the 'bad' category. Respondents favoured uses of geothermal energy for existing agriculture, small industry and electric power for the big island. Export of the power and use by large industry was unpopular. More than half of the sample felt that ownership of the geothermal resource should be with native Hawaiians, a quarter with land owners, 12.5% with owners of the mineral rights and 11% with the state government.

In conclusion the author states that there appeared to be..."a balancing of the potential economic effects of geothermal development with the environmental and social costs of development; and there is considerable polarization of attitudes." This is something that the author says is not uncommon, viz. the attitudes of residents near to the Geysers geothermal field (Vollintine & Weres, 1976) He concludes that "Information about community attitudes is necessary in order to plan geothermal development in a way that is responsive to community concerns and minimises the social, cultural and economic costs

to the community", and recommends that it be a routine part of any new or expanded development.

Visual Impact and Safety

DiPippo does not consider visual impact and aesthetics to be a problem since the structures are low in profile and "can be blended into the natural surroundings".

The possibility of catastrophic events such as a blow out or earthquakes from induced seismicity is acknowledged by DiPippo, but he considers the likelihood of blow outs rare nowadays due to the use of preventer equipment and proper drilling procedures. Strict regulations now apply to geothermal drilling with California's in the USA the most stringent.

On the subject of safety he states that the worst possible accident at a geothermal plant would be far less serious than at a nuclear or hydro electric plant.

10. Conclusion

Geothermal energy utilisation started in the early years of this century before environmental effects were fully recognised and understood and early geothermal power stations created large impacts. Air, watercourse and ground water pollution, together with considerable noise and sometimes subsidence resulted from geothermal use. Gradually, through the application of tougher environmental legislation especially in the USA, the technology has been improved by new designs and equipment. Nowadays the best practise is considerably cleaner and more environmentally acceptable.

Impacts on the environment have not only influenced the technology's development considerably but have also been responsible for the cancellation of projects as happened in Hawaii.

Table 5 Summarising Impacts from Geothermal Energy

Landuse / use of space
 Incompatibilities
 Planning
 Noise
 Visual
 Safety
 Wildlife
 Gaseous emissions
 Liquid Emissions
 Subsidence possible
 Minor earth movements

Chapter 5

Wind

Introduction

Wind energy is now expanding rapidly worldwide with 3500MW of capacity installed. (BWEA Lindley 1994). Its development is very recent, essentially through the mid 1970's and the 1980's. The modern development of wind energy was started in Denmark in the 1920's, but has only been widely implemented since the 1980's, starting with Denmark and California.

To produce substantial amounts of energy, wind energy requires a large number of wind turbines spread out across a large area since it is a relatively diffuse form of energy or low energy flux. The turbines need to be tall structures since the wind flow is much reduced by friction with the ground surface and windy locations need to be chosen, eg hills, ridges or open areas. It is this need for large numbers of energy converters sited across large areas, that initially cast doubt on the environmental practicality of wind energy programmes.

Interestingly, the wind energy industry has since the mid 1970's, through the 1980's to the present time been very aware of environmental issues. This technology's development has taken place concurrently with analysis of its impact and has responded with technical and design evolution.

The extent of the environmental impact of wind energy depends to a degree on the location of the resource and the number of turbines required. The location of the economic resource, eg above about 6-7m/s mean wind speed at hub height in the UK, can correlate with areas of great landscape value (CEGB 1988), or with the more densely populated areas as illustrated in Sweden (Carlman 1986). Both the size and the numbers of turbines required can determine the extent of environmental impact.

The review that follows looks first at some of the literature concerned with the different physical effects of wind energy, followed by a review of some of the literature covering the overall environmental impacts of wind energy. This is a field in which I have published extensively, Clarke (1988, 1989, 1991, 1993) and I have included my own paper in this review where relevant.

1. Visual Impact

The visual impact of large numbers of large structures sited in open areas is to some extent unavoidable.

One of the most informative papers on this subject titled 'Aesthetic Factors and Visual Effects of Large Scale WECS', (Nat. Swedish Board for Energy Source Development, 1980) identifies some of the most important parameters of visual impact from turbines such as the zones of domination and basic rules of human perception. The authors state that visual effects can be mitigated by the use of landscape design measures such as a visual exclusion zone of 10 times the turbine diameter or height and consideration of the

topography in the vicinity of the site.. They identify four basic zones, in relation to distance from wind turbines:

- i) Sweep zone inside the radius of the turbine.
- ii) Extreme dominance or intrusion zone, within three times the height of the turbine.
- iii) Dominance zone, within ten times height
- iv) Zone of visibility, which depends on the height of the turbine and topography.

This paper also describes rules for the visual association of features in the landscape. It is stated that if features are separated by three times the height of the turbine, no visual association will occur, while within this area, features would be visually associated. The effect of topography is also considered and the authors show how a concave hill shape in the foreground can amplify the visibility, and a convex shape lowers the visibility. Other attributes of landscapes are considered, such as whether they are open or closed, depending on the field of vision and extent of visibility.

Rules for turbine siting are suggested, such as the use of vegetation to screen turbines, however, the authors point out that this must not obstruct the wind flow. They conclude that "no simple conclusion can be drawn about the optimum size of wind power units", as the difference in power output allowed twelve 100m high units to generate as much power as fifty-four 50m high units. The authors emphasise that a wind turbine generator group should be designed to fit the landscape's character, "so that a landscape with wind power and not a wind power landscape is achieved."

Altogether this is one of the most significant and generic works on visual impact for wind turbines and landscape design. However, the authors assess the effects of potential 100m high turbines, a size which is not yet being employed commercially, rather than using an existing windfarm and this may distort the results of their study.

The first work in the UK considering the topic of visual impact from wind turbines appears to have been Atkins' report for ETSU, 'First Report on the Visual Impact of Large Wind Turbines' (Atkins, 1983). This study draws on the Swedish work but differentiates between landscapes types in the UK compared to those in Sweden, and also notes the incidence of protected landscapes in windy areas. The authors of the Atkins report also draw attention to the effect of the blade rotation which they state, "can increase the impact compared to that of static structures." In addition they point out that two bladed turbines appear to have a non constant motion, compared to three bladed types. Their report begins to discuss visual impacts in terms of public attitudes. They conclude with recommendations for further research and with techniques for visualisation.

Clearly the siting of turbines needs to be carried out with care and sensitivity so as to avoid overwhelming the landscape. A typical medium sized wind turbine of 250kW has a height of 50 m, with the hub height at 30 m. Large turbines of MW capacity can be 100 m high and can be visible for 25 miles, 40 km in clear conditions (Nat. Swedish Board for Energy Source Development. 1980)

Builtjes et al state that wind turbines need to be spaced out at 5-15 diameters so as to avoid obstructing the wind flow to other turbines in a paper, *'Modelling of Wind Turbine Arrays'*, (Builtjes et al 1980). This requirement to be spaced out adds to the area required.

Verkuijlen and Westra describe another potential visual effect of wind turbines in addition to visual impact; shadow flicker disturbance (Verkuijlen and Westra, 1984). This phenomenon may be caused to habitations in the vicinity of a wind turbine. The authors relate how this phenomenon could, in certain situations cause irritation or even epilepsy in susceptible persons. However, they explain that the effect is only caused when a turbine is sited in the vicinity of a building in a southerly orientation. Even then, the effect occurs only at certain times of the year and for a short period.

Bergsjö et al state that the scale of the turbines can be matched to the landscape (Bergsjö et al, 1982). Cairns and Partners state in their 'Environmental Assessment Report of Aerogenerator Project, Sussetter Hill, Shetland', one of the first Environmental Impact Assessment of a wind turbine development in the UK, that turbine blades should rotate at no more than 45 rpm in order to give a relaxed impression of motion to the observer (Cairns 1986). The authors state that three bladed turbines appear to have a more steady motion than two bladed ones.

On the subject of wind turbine size as a contributory factor to visual impact, there is at present no consensus as to whether the public prefer fewer large turbines or a greater number of smaller turbines. However, studies by Thayer indicate that a wind farm should consist of turbines of the same size and shape in orderly rows respective of land contours and should be evenly spaced (Thayer, 1988). Clarke and other commentators have made the point that visual impacts are perceived subjectively, for example large numbers of pylons are tolerated in the landscape (Clarke, 1988).

2. Noise

Wind turbine noise is generated either by mechanical components such as the gear box and the generator, or aerodynamically by the blades. Berkhuizen, et al in a paper titled *'Estimation of the Wind Energy Potential in the Netherlands, taking into account Environmental Aspects'*, state that noise can be an important environmental impact in densely populated areas and can be a limit on wind energy developments if there are settlements within audible range (Berkhuizen, et al 1986). The authors describe the procedure involved in identifying exclusion categories, ie areas where wind turbines should not be sited.

Hubbard and Shepherd suggest means of mitigation of noise in their paper *'Environmental Noise Considerations for the siting and operation of wind energy farms'* (Hubbard and Shepherd 1985). Mechanical noise, can, they state, be reduced by good design and maintenance and by acoustic insulation. They state that noise reduction at the rate of 6dB(A) per doubling of the distance from the noise source can be used, although there are various complexities such as atmospheric and ground attenuation. In a technical report titled 'Noise prediction programme for wind turbines', by Taylor Woodrow and Institute of Sound and Vibration Research, Southampton University, the authors state that aerodynamic noise is produced by interaction of the blade with inflowing air turbulence, by turbulence at the trailing edges, and tips and is the characteristic rhythmic "swishing"

sound (Taylor Woodrow & Inst. Sound & Vibration 1986). The first part of the report describes measurements from the Bugar Hill test site and the second propeller noise prediction. Formulae are given to predict the source mechanisms. The rhythmic pulse is produced by interaction with the tower when the blade passes it, they state. While aerodynamic noise can be reduced by the use of variable speed turbines, slender blades, whole blade feathering, and careful aerodynamic design, it is generally recognised as more difficult to control than mechanical noise.

Noise is attenuated by distance from source at approximately 6dB(A) per doubling of the distance from the turbine. (Hubbard et al 1985). The extent of the separation zones required will be determined by the ambient noise level and the local noise legislation. Williams states in his PhD Thesis '*A Survey of the wind resource in Cornwall to examine the influence of settlement patterns and topography on the optimum wind turbine size and disposition*', that ambient noise levels are likely to be low in areas where turbines are sited, usually rural areas (Williams, 1989). His study measured the ambient noise levels at 21dB(A) at night and 27dB(A) by day. Williams identified noise as one of the key impacts constraining the development of wind energy.

Standards do exist in the UK for noise emissions BS 4142, being possibly the most relevant (BS 4142 1967). This standard specifies definitions of nuisance as being 10dB(A), and 5dB(A) above the ambient background noise level. However, these standards were devised mainly for industrial noise emissions, and are not very suitable for rural areas with very low ambient noise levels.

A House of Lords Select Committee on Alternative Energy Sources quoted Lindley that close up a wind turbine operating in windy conditions may produce 60-70 dB(A), and at 300m distance this is reduced to 32dB(A) (Select Committee 1988).

Taking these factors into account, a separation distance of 300-400 m from the nearest habitation has been used for a medium size 300 kW turbine by eg Rand and Clarke(1991). The extent of separation distances can determine the size of the available resource and so reduction of turbine noise is therefore an objective of wind energy R & D programmes, with considerable progress being made with modern machines.

3. Safety

Egwertz calculated the probability of wind turbine failures in a paper '*Safety of Wind Energy Conversion Systems with Horizontal Axes*'. He states that the main risks are that ice, blades or blade fragments may become detached and thrown some distance. The risk of a serious structural failure is considered to be relatively low by Egwertz at 10^{-5} per year per turbine. In the event of failure, a wind turbine in common with any other energy plant can pose some risk of danger. Turbines should therefore be sited at a distance from habitations and property (Egwertz, 1981). There have also been failures resulting in tower collapse and fire, but blade or fragment throw is more likely.

The risks have been theoretically estimated at 1 serious structural failure per 10,000 WTs each turbine having a 30 yr life, by Maqueen (Maqueen 1983) in a paper '*Risks Associated with wind Turbine Failures*'. This probability has been used by Maqueen, together with maximum throw distances, to estimate the probability of impact in the area around the

turbine. He states the reasons for wind turbine failure as ice blades thrown or blade fragments thrown. He states that the distance of 'fragment throw' depends on the tower height, the fragment angle, and the tip speed. Maqueen calculates the risk of being hit within 210m, is 10^{-7} , which is comparable with being hit by lightning. The maximum throw he estimates is 371m, with a probability of $10^{-5}/m^2$.

Since these theoretical studies were carried out, there has been much experience of turbine operation. Williams, in 1989 considered that some of the predictions were over optimistic and that blade failures are likely to be more frequent (Williams 1989). The most dangerous event is he states, 'running away' when power is disconnected, eg for maintenance and Williams recommends incorporation of dynamic, self-excited electrical braking designs as well as synergistic wind drag devices.

Rand and Clarke state that a typical separation distance of 300-400 m for a medium sized turbine for visual and noise reasons should be adequate for a safety buffer zone and so would not add to the requirement for space (Rand and Clarke 1991).

4. Electro Magnetic Interference

Wind turbines can interfere with radio transmissions and though this is not usually a problem, it can be where vital transmissions services are concerned. Chignell describes the mechanisms in a paper *'Recommended practices for wind turbine testing and evaluation, Electromagnetic Interference'* (R.J.Chignell 1986a). He explains how the turbine can act as an unwanted relay transmitter, sending a signal by a second path which varies periodically as the blades rotate. To avoid problems of interference, he recommends a full survey of all the transmissions present should be carried out. Chignell states that attention to turbine design and the choice of non magnetic materials such as composite materials or wood for blades can reduce the chance of radio interference. Where it is unavoidable, he states, a booster receiver / transmitter can be installed or the turbine can be resited. Television and radio transmissions are most likely to be affected according to Chignell, since their coverage is universal.

Chignell also draws attention to the need for a 1 km and a 5 km separation distance required for aircraft navigation systems such as VOR and ILS. He states that microwave transmissions must not be interrupted in any way, although the line of sight beam is very narrow, eg a few metres, in another report *'Electromagnetic Interference from Wind Turbines , -A simplified guide to avoiding problems.'* Largely a simplified repeat of Chignell (1986a) and Chignell (1986b) for the NEL National Wind Turbine Centre (Chignell, 1987). Williams notes that aerial masts will tend to be sited on hills and ridges which may be the same areas where wind turbines are sited, (Williams 1989).

Dutch organisations have compiled guidelines of 100 m separation distance from the path of the link in 'Legislation and Regulation in the European Community Member States'. (CEC 1987)

5. Wild Life

Only birds are considered to be affected by operating turbines. This can have an effect on turbine siting through the separation zones required from nature reserves and habitats. The large rotating structures of wind turbines can obstruct the flight of birds. However, Mead

states that birds have been observed flying through rotating turbines unharmed and can usually react to them calmly (Mead, 1982). Mead makes theoretical calculations on bird impact, bird species and habits, based on large wind turbines along the East coast, and on the maximum damage that can be sustained to turbines in his paper *The possible impact of wind turbine generators on flying birds*, for the British Trust for Ornithology.

Some of the most thorough observational work on the effect of wind turbines on birds was carried out by Winkelman in the Netherlands (Winkelman, 1984). Winkelman in her report *'Bird Hindrance from Medium sized wind turbines'*, relates that her study showed that only one per cent of the birds' reactions were made in panic, and most of the reactions were calm and gradual. Groups of turbines were found to be more visible than single ones, she states. Winkelman concludes that in conditions of good visibility in daylight, the effect on birdlife is negligible. No conclusions were drawn for low visibility conditions though.

The RSPB in *'Conservation Topic Paper, No 22'* report that they and the NSHEB, had not as yet recorded any strikes or effect on birds from turbines at the Bugar Hill test site in the UK, in a report of Bugar Hill birdlife monitoring (RSPB 1988).

However, Davidson in the USA, reports that there have been recorded bird strikes at Altamont in California, in an article in *Windpower Monthly*, and that a study by the Californian Department of Fisheries and Wildlife into the effect on raptor birds has been announced (Davidson 1988). The potentially detrimental effects of wind farms on birdlife and nature reserves, have caused Berkhuizen et al to suggest a separation distance of 300m from nature reserves in the Netherlands, in their paper *'Siting Procedure for Large Wind Energy Projects'*. (Berkhuizen et al, 1988).

Siting

In a paper titled *'The environmental and community impacts of wind energy in the UK'*, Rand and Clarke, identify the rules governing wind turbine siting (Rand and Clarke, 1991). They state that turbines are perhaps best sited on open arable or grazing farm land, or heath and moor land, and that their use is incompatible with habitation, built up areas, forestry, airports, military zones, designated amenity areas and quarries, earthworks etc.

6. Land Area Required

This is the only environmental resource apart from visual amenity actually consumed by wind energy. The CEEB produced Publicity Material which includes the calculation that to produce power equivalent to a nuclear plant such as Sizewell in the UK, an area of 729 km² might be required (CEEB Publicity Material, 1986), which was used to cast doubt on the feasibility of wind energy. However, the BWEA Factsheet *'Wind Energy Some Questions Answered'*, states that only about 1% of this area is actually used by the turbine base, and the remainder can be used for farming (BWEA, 1990). With the access road this fraction increases, some sources citing it at 3-5%. For example, Gipe cites the Velling Maersk Taendpibe wind plant on the west coast of Jutland in Denmark, as using 3.2% of the landspace and he says that most of that is for the roads that were already present when the plant was built (Gipe, 1991). Gipe also quotes the US Bureau of Land Management which estimated that for one wind project that was monitored, 10% of the soil was disturbed by the wind plant.

It is easier to conceive of large numbers of wind installation in dispersed groups. Holt et al estimated the resource available based on an installed capacity of 4 MW / km², in a paper '*Estimation of the onshore wind resource in England and Wales*' (Holt et al 1989). They concluded that 1200 km² was available for wind sites giving an equivalent plant capacity of 1700 MW.

Bell estimated that 12.5% of UK land area was unconstrained by physical and institutional constraints (Bell 1990).

Clarke assuming conservatively, that similar wind speed distributions hold for Scotland, estimated that to produce 10-20% of the UK's electricity from wind energy might require turbines to be sited across 2-4% of the land area of 250,000km² of the whole of the Britain (Clarke 1988 & 1991).

7. Public Acceptability

Experience and research has resulted in better knowledge of the physical impacts of wind energy on the environment, but inevitably impacts will tend to be perceived subjectively, depending on the attitude of the observer. Just how many turbines the public will tolerate in the landscape is an unanswered question, and public attitudes will in the end be one of the final constraints upon how much energy can be generated from the wind. Carlman in a study on '*Public Opinion on the Use of Wind Power in Sweden*', concluded that in general, the public's response to wind energy is positive (Carlman 1986).

Lee et al, in one study in the UK, '*Public Responses to the Siting and Operation of Wind Turbines*', found that 52% of its respondents favoured the expansion of wind energy (Lee et al 1989). Rand and Clarke, however, point out that if wind energy proposals are not sensitively handled, they can encounter opposition, causing projects to be delayed or even cancelled (Rand and Clarke, 1991). The causes of this opposition they state, may lie in poor siting of turbines with regard to environmental rules, siting in designated or valued areas, inadequate consultation or communication, or a failure to distribute the costs and benefits of the development adequately. Additionally, they point out that developers may believe themselves to be constrained in choice through either economic pressures or inadequate investigation.

Adherence to environmental siting rules and the development of planning guidelines for local authorities should reduce the incidence of opposition due to physical impacts. Proper communication and consultation with the local community is needed to help allay unfounded fears and suspicion, and sufficient time should be allowed for this.

Rand & Clarke note that the most successful means of diffusing opposition appears to be to employ mechanisms to redistribute the costs and benefits of wind energy developments such as compensation, reduced electricity power rates, or local ownership and investment in wind energy. (Rand & Clarke 1991).

Palmer in a paper for a BWEA workshop '*4MW per Month: the Economics and Reliability of Private Wind Energy in Denmark*' states that 140 MW of grid connected wind energy in Denmark, was privately or co-operatively owned and operated at the beginning of 1989 with consumers able to buy shares in local developments (Palmer 1989). Palmer states that 1% of the Danish population had invested in wind energy in the previous 10 years with investment rates growth at 12,000 new investors per year. He

remarks that in contrast with the utility developments, locally owned and planned wind farms enjoy considerable local support.

Rand and Clarke state that developers need to be able to respond flexibly to public feedback with for example alternative sites possible in lower wind speed areas. Wind energy developers can find means to tap into the considerable goodwill that exists in the environmental movement as well as the general public but they will need to tread carefully.

8. Planning

Wind energy, as the literature acknowledges, is a 'diffuse' or relatively low energy flux energy source requires large numbers of converters to produce significant amounts of energy. Grid connected wind turbines are usually of only a few hundred kW capacity, eg currently in the range 150-500 kW. Even when grouped together into wind farms, in quantities ranging from five to 103 turbines, at the largest wind farm in the UK at Landinam, the maximum total generating capacity is only about 40MW. This is still very much smaller than the capacity of a conventional fossil or nuclear station of approximately 1-2 GW.

This requirement results in a large number of siting decisions and a particular accent on the planning process. Whereas early wind energy developments in the USA were virtually free of environmental constraints, the more densely populated countries of Europe have required wind energy to be heavily regulated.

Bell et al in their study *'Land Constraints on the Wind Energy Resource in the UK'* emphasise that in the UK and especially England and Wales, much of the wind resource occurs in areas already designated and protected for their landscapes and amenity use, such as the National Parks and Areas of Outstanding Natural Beauty, AONB's (Bell et al 1990). This study, by the Institute of Terrestrial Ecology comprised a thorough km² by km² survey of UK land use, for wind energy purposes, using the large data base developed there. Bell et al assess the availability of the land areas on the basis of physical, institutional and environmental constraints. It was found that 12.5% of UK land area was unconstrained by physical and institutional constraints and that there were 142,912 potential sites for 33 m diameter turbines in the UK.

The conflict of land uses that wind energy developments can entail, needs to be resolved through the planning system. Piepers in a paper titled *'Prospects for Wind Energy in the Netherlands'* shows that this can be a lengthy process, which can seriously delay the achievement of wind energy capacity targets, as has happened in the Netherlands (Piepers, 1990.)

Advance planning policy decisions designating wind development areas or no-go areas on a regional or even national scale can help avoid some of the delays.

De Bruijne et al describe how an integrated wind energy programme in the Netherlands, identified 20 areas outside of environmentally sensitive areas where wind energy development could be encouraged. (de Bruijne et al, 1988).

The need for integration of wind energy development proposals into planning policies has been addressed by the UK government with the publication of guidelines for planners, in *'Planning Policy Guidance Note 22'* (PPG22, 1993). This gives advice to planners on

wind energy and how to accommodate it through local plans, structure plans, designated areas, and Environmental Assessment procedures. The latter topic is addressed also by the '*Draft Circular on Implementation of the EC Directive on Environmental Assessments*', from the Department of the Environment, which provides criteria for the need for Environmental Impact assessments (Dept Envir. 1988).

PPG22 deals with several renewable energy sources but is mostly concerned with wind energy, landfill gas and incineration. The approach adopted is to provide information but not specific rules, ie much is left to local planners' discretion.

Edwards draws attention to other issues of wind energy and planning in a paper '*Considerations to be taken into account when planning a wind farm*'. He instances wind rights, and land owners rent, which he states, need to be resolved. (Edwards, 1990.)

General Environmental Impacts from Wind Energy

The more specialised topics of the literature reviewed above have been collected into literature describing the overall effects and impacts from wind energy. This type of literature assesses the importance overall of environmental impacts to wind energy and how it might shape the technology and its implementation.

9. Swift-Hook

'*Wind Energy and the Environment*', edited by Swift-Hook D.T. 1989, and published by Peter Peregrinus on behalf of the Institute of Electrical Engineers, is important as the serious comprehensive work on the environmental impacts of wind energy. It is a compilation of papers, largely from the conferences of the European Wind Energy Association, and as such is a technical and academic approach aimed at design engineers, wind energy developers, consultants, and planners. This is to be expected from a learned body whose purpose is the development of a body of knowledge in the industry. International sources are used with experience in Netherlands, in Greece and in Sweden cited as well as UK- although at the time it was written there was little experience of commercial wind energy and no wind farms in the UK.

The foreword contains the rationale for this compilation of papers from EWEA Conferences, -"Environmental and institutional concerns are the only ones now standing in the way of the wide spread exploitation of wind energy." Swift-Hook extols the advantages of wind energy as "long recognised as benign because it is safe, non polluting and does not deplete the world's energy resources." He also claims in the foreword that "wind energy..." is now (1989) cheaper than any other method of generating electricity than any other method "on good windy sites", a view that is disputed elsewhere, even in 1994. His view is that as answers to questions of technical and financial matters are now emerging from wind farms, the biggest question marks that utilities are now raising "are to do with environmental problems and siting considerations".

As Swift-Hook states, "wind farms cover considerable areas of countryside, and although they occupy only a tiny fraction of the land, one or two per cent, their presence will be noticeable over the whole area. Noise and television interference will cause objections and

they will be visible at quite a distance and the public will need reassurance about other matters such as safety."

After the chapter on the technical and economic status of wind energy, chapter 2 deals with how the Netherlands planned for wind energy (Berkhuizen, et al 1986). A model of existing land use was used together with turbine separation distances from different categories of land use to generate exclusion zones and areas suitable for development.

In fact, the book concentrates on noise -Chapters 5, 6, 7, & 8 all on noise out of 17 chapters possibly reflecting Swift-Hook's view that this is the most important environmental impact of wind energy (see also Williams 1989). The topic of electro magnetic interference has two chapters devoted to it, using sources such as Chignell, reviewed above and there are two chapters on safety, one on Dutch safety regulations and one on blade throw.

Swift Hook believes that although the utilities are cautious in their approach to wind energy, they are only too well aware of the advantages of a method of generation that produces no acid rain or carbon dioxide and radioactivity, a renewable source of power that does not deplete world reserves. "It is simply that they have long experience with environmental problems and public objections caused by their present types of power plant." But just because wind farms could not "blight the forests of Germany nor the lakes of Norway" (as for example fossil fuel generation is thought to do), "that does not mean that they will have no environmental effects of their own" Swift Hook states. He considers that the diversity of wind energy which involves civil, mechanical and electrical engineering, aerodynamics, control and electronics, materials science, mathematics and physics makes the subject challenging. The environmental problems of wind energy, in his view, involve an even wider range of subjects including less quantifiable subjects such as public acceptability and legal constraints.

Chapters 15 & 16 are studies of public attitudes, the former covers experience in Milton Keynes with a small turbine in a residential area. One chapter is devoted to legal aspects of wind energy exploitation: an EC perspective.

Swift Hooks' emphasis on this broad range of subject matter is pertinent, since although this is in the nature of environmental issues, it is particularly relevant to renewable energy. Swift-Hook is generally optimistic about the capability of the wind energy community to tackle the environmental problems of wind energy successfully, citing the successful development of low noise jet engine turbines as an example of what could be achieved with turbine rotors. As an example of this, Chapter 9 deals with an advanced wind energy converter, of a variable speed type.

However if public acceptability of a significant scale of wind energy does not prove to be possible, Swift-Hook leaves open the prospect of a significant role for wind energy by including a paper on offshore wind generation in chapter 17.

Two key physical impact omissions are the lack of any papers on visual impact or on the location of the wind resource. Visual impact, often considered to be too subjective to be dealt with in any systematic way, is emerging in 1994 as a prime impact. There are relatively few works on the topic (see above) considering its importance. The other

missing issue -the location of the resource, is surely a significant indicator of what impacts are likely to occur since these depend on the existing land uses.

Institutional issues such as planning policies or the attitude of nature conservation bodies are not covered either, issues which have subsequently proved important to the development of wind energy.

Some five years later, with up to three years' experience of wind farms in the UK this work may appear a little dated in places, for example the section covering an experimental "advanced turbine" work on which has apparently been discontinued. However, most of the papers are still very relevant. While the industry developed its awareness of environmental impacts of wind energy in this time, the subject remains important to wind energy.

10. Clarke

Another general work on the consequences of environmental impact for wind energy is the 132 page report *'Wind Farm Location and Environmental Impact'* by the present author, published by NATTA, the Open University based network (Clarke 1988). This report aims to bring together the individual physical and social environmental impacts in order to make an approximate assessment of the feasibility of a wind energy programme. Before any development of wind farms had been started in the UK, in the 1980's, wind energy had gained a reputation as an unpractical energy option, although the considerable size of the resource was recognised. The sceptics were doubtful that wind energy was worth developing on the grounds that many thousands of turbines would be required for any significant programme, and that sufficient land space would not be available. It was also thought that the public would not accept wind turbines. My aim was to examine these issues in more detail.

The introduction stresses that wind energy is becoming economic and the technology is mature enough to provide fairly reliable energy, but that wind energy has some relatively novel characteristics in terms of environmental impacts, and is (was) a novel technology. The NATTA Report considers the issue of wind energy's environmental impact drawing attention particularly to the location of the wind resource, which at the time had not been properly identified. Although it was known that the windy areas were in the North, West, upland and coastal areas, there was little published material which showed this or drew the consequences from it. Drawing on published resource studies such as 'The UK Wind Energy Resource' ETSU R20, (Newton, 1983), and combining several sources, the NATTA report identifies in broad terms the areas where wind energy is likely to be viable showing the first countrywide maps of the wind energy resource. Thereafter, the author describes each of the physical impacts of wind energy in turn using published literature sources and identifying pertinent factors in order to build up a rule base for the parameters of wind energy siting. This study, in common with many other commentators perceives the most important physical impacts to be visual impact and noise, but an important unknown factor is, the report states, public attitudes. After considering the physical factors, the social issues such as public attitudes and planning are discussed. Planning is seen in this NATTA report as an area requiring attention, due to the large number of dispersed planning decisions required and the lack of any overall coherent policy (at the time) by

central government in response. The report notes that deficiencies in planning policy could adversely affect public attitudes, -which has been borne out by events recently. The report includes a section on wind turbine siting so as to minimise impacts, and towards the end this is shown in checklist form. The report recommends that no developments should be carried out in National Parks, Areas of Outstanding Natural Beauty, or other nationally designated areas. The third section of the report describes several case studies to try to illustrate the processes, and conflicts that wind energy projects can entail.

The report states that three groups are addressed: the wind energy industry, planners, and the general public and perhaps as a consequence, the approach is largely qualitative using published material, rather than a rigorous quantitative investigation. The report falls between two stools because of this, being written neither in an academic style, eg with regard to references, nor being sufficiently short and accessible for popular presentation.

The report concludes that there will be enough land area for between 10-20% of the electricity of the UK to be produced from wind energy, despite the conflict with designated areas. The report estimates that this may require about six thousand wind turbines to be spread across about 3000-6000 km² of the land area. These estimates were in general borne out by Bell (Bell et al 1990.) However, the report acknowledges that most of the wind capacity will be some distance from demand centres, although the economic cost of this is not considered.

The report has proved relatively influential due both to its timing and to the way existing work was brought together and conclusions drawn, which have a relevance for policy issues. The report helped to fill gaps, in wind energy knowledge at the time, after a period of very rapid development. The timing of this report proved important as the electricity supply industry was about to be privatised, and a subsidy for non fossil fuel supplies was being developed, thereby providing the opportunity for wind energy.

Six years later the report can seem to be dated in places, for example the section covering the case studies, though much of it remains very relevant, for example the response of Nature Conservation Bodies, or the public to wind energy proposals.

Conclusion

From the above it can be seen that there are impacts from wind energy and that these impacts are certainly important to the industry both constraining it and limiting the choice of sites. However, these effects impact mainly on the human environment, apart from some effects on birdlife. Both technological improvements and development of siting rules can be used to substantially reduced the impacts experienced. At the same time, the inevitable visual impacts have sometimes generated sufficient opposition to block individual schemes, though by and large this has not prevented wind sites being found elsewhere. Notable exceptions are in very densely inhabited areas eg Netherlands where the 1GW target for wind energy has recently been reduced to 450MW due to inability to find further sites. (WindPower Monthly 1994). Noise has proved to be the other major impact, as the literature predicted. The complexity of this issue has resulted in some developments generating complaints about noise, however, the subject is more amenable to technological solutions than visual impact.

The high profile of wind energy's impacts led to an early recognition on the part of governments and developers that this potential barrier needed to be researched and investigated. The initially seeming fantastical idea of thousands of wind turbines generating significant amounts of energy has probably stimulated work on environmental impact, since much of the apparent impracticality of wind energy stemmed from anticipated environmental effects.

Table 6 Summary of Wind Energy Impacts

Visual

Noise

Electro Magnetic

Safety

Wildlife

Landuse / use of space

Planning / Compatibilities

Chapter 6

Tidal Energy

Introduction

Tidal energy, as conceived in barrage schemes, utilises the rise and fall of tides to produce a head of water behind the barrage which is then passed through turbines in a similar manner to low head hydro electric schemes. Another possibility which has hardly yet been developed beyond the prototype stage is tidal flow, where the flowing water would turn turbines but no barrage would be employed to maximise the head. Baker states that the total potential world resource for tidal energy comes to 2.6 TW, or almost one third of current global energy consumption, (Baker 1984), while the Bay of Fundy represents approximately 1% of total resource. He explains that the size of the tidal range depends on the tidal wave resonance with coastal shapes and length of oceans. (Baker 1988)

Only the Rance project has been built in full scale (240MW installed), and there are only, as far as the author is aware, another three small scale pilot plants in existence, in Canada, Russia, and several micro scale plants in China. The total world installed capacity is about 260 MW. Despite the very small number of tidal schemes built, there is an extensive literature on the subject of tidal energy and its environmental impacts. This may in part result from the large scale of tidal plants and the irreversible nature of such projects. In the UK, the very large 7.6 -8 GW tidal power resource of the Severn Estuary has been the subject of numerous studies since the 1920's, and 1930's. Its scale would make it strategically important in future UK wide power plant plans.

The literature selected here covers largely similar themes, sedimentation, and water quality, effects on aquatic and bird life, etc. However, over the period covered, progress in the development of understanding of environmental impacts can be seen, and the technology and operation of a barrage has been modified to some extent. Unfortunately, due to the paucity of realised schemes, most of the literature is of a hypothetical, modelled nature. Two papers concerning the Rance barrage are included in this review, and one about environmental impacts at Annapolis scheme in Canada and one of a small Russian scheme. All the others are studies of anticipated or potential impacts which may prove to be fairly reliable, but may also contain assumptions and gaps in knowledge. The complexities of ecological interactions cannot necessarily be reliably modelled, since relatively small changes in conditions may cause significant changes in ecological communities. Nor are conditions uniform, each estuary being to some extent unique in its conditions. For these reasons the dependability of the literature predicting impacts has not been proven.

1. Baker

'Tidal Power', by Baker, is a comprehensive text on the theory, mechanics, resource and world development of tidal power (Baker 1988). Environmental impacts are dealt with in 21 pages out of 243.

Baker states that the book attempts to "pull together the work that has been done on tidal power in the last 60 years" an indication of the age of tidal schemes. (The small scale use of tidal energy for milling of course goes back for hundreds of years.)

Baker himself worked as a Project Engineer for Binnie and Partners when the Department of Energy commissioned them to do a study of tidal power from the Severn Estuary in 1978. His concerns reflect this engineering based viewpoint with a concentration on the theory and mechanics of tides and the design, construction and economics of barrages. Baker acknowledges the work that has been done in other countries such as France, Canada, South Korea, India, Brazil, China and the USSR.

Baker's first section covers the origin of the tides, diurnal tides, coriolis force, variation of tidal range, tidal constituents, surge tides and tidal data, in a section with considerable theory and mechanics of tides. It goes on with a section on the operation of a tidal power barrage, its principle components, ebb generation, flood generation, ebb generation plus pumping at high tide, two-way generation, and two basin schemes. There is a section on turbines and generators, describing the different designs and their construction and performance.

Following this a section describes construction of the barrage, the forces it would be subject to, from tidal range currents, to wave forces. Baker describes different designs of sluices and their operation, then embankments and plain caissons are considered under the topics of experience elsewhere, materials and their transport and costs.

However, the book is concerned mainly with barrage schemes, though tidal stream technology is mentioned. This work is strong on theory and the mechanics of tides across the oceans. Many equations for engineers are included and it has a good coverage of world wide schemes and the potential for schemes. Economics are well covered within the scope of the topics covered.

However, the question of the relatively small uptake of this technology should perhaps be better addressed, given that the technology is well proven by more than 25 years of successful operation of the Rance barrage which is the only commercial medium / large scale tidal plant in existence. The reasons, economics, the long construction lead time and pay back period, the relative scarcity of sites in many parts of the world, and environmental impacts are discussed.

Baker states, in the chapter on environmental impacts, that the reduction in volume of water leaving and entering the basin, is a fundamental change that will have profound effects on the environment in its broadest sense. However, "predicting the consequential changes in water quality and then on through the ecosystem, and assessing their importance is much more difficult", he states.

Baker covers environmental impacts under the topics of water quality, turbidity, biodegradable pollutants, conservative pollutants, dissolved oxygen, bacteria, sediments, effects on nature, fish, birds and mankind.

He acknowledges that experience of tidal power schemes to date is limited, with the Rance scheme starting to generate in 1966, and the Annapolis scheme in 1985 and states that no formal assessment of possible environmental impacts was made before construction of the Rance barrage, but that the Annapolis Bay scheme has been the subject of environmental studies.

Water Quality

Discussing the physical impacts in detail, Baker states that water quality, in particular the salinity, has been affected by tidal power schemes. He explains that in a tidal estuary such as the Severn, salinity varies naturally between about 30 g / litre and 10 g / litre over a 60km stretch, but with an ebb generation barrage, a this variation would occur but would be about 20 km further seawards.

Baker describes another important change, the turbidity that could be reduced by about half, since a tidal power scheme would halve the tidal range. At present turbidity is relatively high he states, due to the 30 million tons (spring high tide) to 3 Mt (neap low tide) of sediments suspended, compared to the river's annual load of about 1 million tons. Much of this sediment would be deposited, but he explains that there are considerable complexities in modelling this. Due to the longer 'quiet period' at high water, Baker states there will tend to be settlement of fine sediments inside the barrage and reservoir. This says Baker, suggests a mechanism for removing fine sediments from the basin, as the currents will not be sufficient to re-suspend them. He states that re-suspension will tend to be caused by wave and wind or even heavy rain, and would move sediments to sheltered areas.

Baker notes that lowered turbidity will result in more light reaching plants and encourage growth and biological agents such as algae and salt marsh vegetation would also help remove fine sediments from suspension.

Baker draws the tentative conclusion, "that turbidity will be reduced to a level that can be sustained by the rivers feeding the estuary and from the sea, but will be liable to temporary increases during storms".

Biodegradable pollutants

Baker cites a hydrodynamic model of the Severn Estuary (Institute for Marine Environmental Research, 1980,) which shows that a barrage would have little overall effect on biodegradable pollutants in comparison with the changes that already occur due to tidal range and fresh water flow. Organic pollutants, he states, such as sewage, wastes, ammonia and bacteria might however, stimulate blooms of algae and plankton, especially with the decreased turbidity, but would decrease thereafter as the new ecosystem conditions were absorbed. He states that new animal communities of zoo plankton, mussels, wading birds, etc feeding off the increased biological productivity would become established.

Conservative Pollutants

Baker describes these as pollutants not affected by biochemical decay, ie inorganic chemicals produced mainly by industrial activity. He states that substantial quantities of metals such as cadmium, chromium, zinc and lead, and non metals such as arsenic are discharged into the Severn estuary. The main method of dispersal he notes, is dilution and dispersion and not flushing out to sea. He states that the effect of a barrage on these pollutants will be that nickel wastes are predicted to increase by 50% during low or average river flows reflecting the importance of river flows to nickel dispersion. Tidal flows are more important for cadmium dispersal which is mostly released into the estuary and cadmium concentrations may increase by a maximum of 50% but are, Baker observes, at low concentrations already, viz one part in 10^9 .

Baker identifies the location of a release of a pollutant as an important factor. Removal of pollutants from circulation is he states, complex, eg organisms such as shellfish, deposit heavy metals in their shells, while undissolved pollutants can attach themselves to silt and clay particles and settle out. He points out that a barrage would interrupt some of these processes.

Dissolved Oxygen, Bacteria and Sediments

As with river life, the amount of dissolved oxygen is crucial to marine life in the estuary. Baker states that models predict little effect on dissolved oxygen apart from a slight reduction over the upper 30 km of the estuary.

The author states that dispersal of sewage effluents could be affected by a barrage due to the reduced flow however, because sunlight is one of the main agents of bacteria degradation, and due to raised low water levels, a barrage is also predicted to have a significant beneficial effects on bacteria and water quality.

On the subject of sediments, Baker points out that most estuaries with large tidal ranges usually contain great quantities of sediments, although the Rance estuary is untypical in having little sediment. Two mechanisms exist he states, for moving sediments, firstly flood tides moving sediments upstream, and secondly, the river bringing sediments downstream. He notes that estuaries tend to be filled from their uppermost reaches downwards, although local variations over lie this general pattern.

Fish

If the tidal barrage plant is to be used as an ebb flow barrage only, Baker states, fish will not be hindered or obstructed in passing upstream, when the sluice gates will be open to make the barrage almost 'transparent'. If fish do pass through freewheeling turbines they should not suffer stress, he states, however, if the turbines are used in reverse to pump, stress may be caused. Baker states that passing downstream, though, the only route through the barrage will be through the turbines. He describes how a fish must survive an acceleration to 10 m/s speed and a pressure drop equivalent to a 20m change in water depth. In addition, he says the fish may encounter the distributor guide vane blades edge on. This he notes, is very similar to many Hydro Electric, low head plants, and experience has shown that most fish are capable of passing such turbines and ones with greater velocities, pressure drops, and rotation speeds. He cites an 85% plus survival rate, (Solomon 1988), which he considers "not an undue obstacle". The Annapolis Royal

prototype turbine has he notes, caused a proportion of the fish to be beheaded, which could be due to the centrally positioned vanes.

Baker states that for the Severn barrage, a fish pass or ladder has been suggested for small fish near the surface, though it would have to be a floating type as water levels change continuously. Baker concludes that "a tidal barrage with sympathetic design should not present an unduly severe obstacle to migrating fish", and that lower turbidity and more stable sediments should benefit commercial marine fish and provide better conditions for breeding. (Riley & Symonds 1988).

Birds

The author recognises the great importance of large estuaries to wading birds, especially on their annual migrations when they fly huge distances and replenishing their energy becomes crucial. Very large numbers of birds he states, may arrive at once eg 100,000 in some estuaries, to feed on invertebrates on the mudflats.

Baker states that the consequences of a barrage, which would raise low water levels to about mean sea level, and a high water stand, are that the intertidal feeding area would halved due to permanent submergence, and the feeding time would be reduced. He notes that for this reason, the RSPB has opposed tidal power development in any estuary (Ferns 1988).

However, Baker believes that the picture may be "less black" since the Severn Estuary, is he states, not in fact very biologically productive due to the mud movements and turbidity. His view is that a barrage would reduce mud movements and turbidity with the result that the estuary would become more productive, which could then support a larger bird population. He states that the stabilisation of sands by deposited mud and plant life, together with the fact that birds tend to feed very near the waters edge and move with the incoming waters means that the changes may not be detrimental. Baker concludes that in estuaries with very large tidal ranges, tidal power schemes should not have a detrimental effect on wading bird populations.

Baker also mentions the "unpalatable fact" that human sewage effluents do contribute major nutrient sources attracting birds and also that the man made tidal reservoir for cooling for the Oldbury nuclear power station, is now an SSSI due to the birdlife it attracts, although he notes that the Nature Conservancy Council concluded it would oppose the building of the Severn Barrage.

Effects on Mankind

Lastly Baker ends the chapter on environmental effects with a brief section on the impacts to humans. Visual intrusion is included with the barrage described as a relatively unobtrusive low barrier not unlike a low bridge, which would be seen only by those relatively nearby. He states that little noise is produced by the barrage and its source would be some distance from any habitations. Appreciation of the increased standing water with much less mudbank and sand at low tide will be a subjective matter says Baker, noting that recreation is a possibility on the inland lake with its reduced currents. Apart from construction of the barrage, he states that the effects on industry would depend largely on the amount of shipping using the estuary.

Baker thus takes an essentially optimistic view of the constraints environmental impacts might impose on tidal energy, describing most of the changes as either tolerable, or even beneficial. Given some of the responses to Tidal Power schemes, see also Chapter 8, Baker may appear not as an impartial observer but an enthusiast. The cause of the high environmental impacts, -the need for a barrage to increase the head, which in turn also helps to make the economics relatively poor, is less adequately explored.

The limitations environmental impacts could impose on tidal energy, given the magnitude this barrier is assuming in the UK is not revealed. Nor is sufficient flexibility shown in the approach to design, eg how to mitigate impacts such as retaining mud banks.

2. Shaw

Shaw, covers the environmental issues of tidal barrages thoroughly in '*An Environmental Appraisal of Tidal Power stations : with particular reference to the Severn Barrage*', a 220 page collection of eighteen papers on studies investigating individual impacts in depth (Shaw1980). The topics discussed include both physical, biological and ecological issues as well as construction and some social issues though the emphasis is on physical and ecological issues. The headings are the physics of water movements in the Severn estuary, the influence of the Severn barrage on tidal regime, sediment dynamics, drainage and land quality, possible biological effects, intertidal ecosystems an modelling, pollution, impact on wading birds and their distribution, fisheries, geology civil engineering and construction including selection of materials and lastly social and recreational habits. Shaw, writing in 1980, states controversially that tidal energy is the only proven alternative to thermal generation. He states that there is "remarkable latitude to improve designs using the most recent advances in offshore construction methods", to bring down the construction costs and improve the economics. He accepts the importance of environmental issues stating that "it has long been recognised that energy production and preservation of the natural environment are often in conflict". Shaw remarks that the challenge is to select from available technical options those that provide for societies needs without economic penalty, and accepting the consequences, while recognising that perceptive design and small extra investments can usually improve the end product. He emphasises the extremely multi disciplinary nature of environmental investigations of tidal power schemes. Although considering primarily the Severn estuary, Shaw states that there are environmental lessons that apply to all tidal schemes, although each is unique in its site and to some extent in its conditions. Assessment of different sites is given considerable attention by Shaw. No effort is made to bring the different contributions together, as Shaw admits, and there is no general conclusion about whether tidal power schemes are environmentally acceptable. Nor is any attempt made to rank the impacts. Generally this work, collecting together different specialisms, represents a useful interim stage with most of the contributors arriving at tentative conclusions only and calling for more research. The book essentially a compendium of ongoing work on environmental aspects.

The parallel with low head hydro power technology is brought out by Langford whose focus is ecological issues.

3. Langford

Langford's 'Electricity Generation and the Ecology of Natural Waters', reviewed in the Chapter 2, also contains references to tidal energy (Langford 1983).

Langford draws attention to the fact that "experience of actual ecological changes resulting from tidal hydro electricity generation is limited". He states that the changes caused by the impoundment of tidal areas are not fully known, but that since substrates upstream of barrage would not be exposed so often as would occur naturally, temperature changes would be reduced. Langford states that an impounded estuary might develop some thermal stratification, though this would be complicated by freshwater flows and restriction of incoming saline waters.

On the subject of tidal movements, Langford notes that the maximum tidal amplitudes vary globally from 0.5m to 14-15m in areas such as Bay of Fundy. Tidal power schemes, he states, will almost certainly disturb the normal tidal patterns at least inland or upstream of a barrage with the littoral (shore) zone in the reservoir reduced since the normal tidal movement will be less due to removal of energy. He also notes that wave motion will be reduced by a barrage, and silt deposition will be increased and scour upstream reduced. Downstream of the barrage, Langford states that scour will be increased at turbine outlets which has eg removed some sand banks on Rance estuary.

He states that in tidal waters oxygenation is 20% lower than in fresh water due to the salinity, and supersaturation may also occur. He states that oxygen stratification in estuaries, reflects salinity stratification with lower oxygen levels in the lower more saline layers.

Much detailed research on specific topics such as effects on fish or birds of tidal energy has been carried out and the paper below is included as a representative of such specialised studies.

4. Solomon

Fish Impacts

'*Fish Passage Through Tidal Energy Barrages*' is a detailed and specialised academic report commissioned by the Department of Energy, as part of the environmental studies of the Tidal Energy Research Programme managed by ETSU, the government's R & D institution (Solomon 1988).

It is a report of a desk study of the likely problems of fish passage through turbines and sluices, and possible interference to migration. The work draws on published literature, unpublished reports, visits to hydro electric schemes, including tidal plants and discussions with fisheries biologists, engineers and turbine manufacturers.

The author covers the subjects of barrage designs, the fish affected, sources of damage to fish, levels of mortality in turbine passage studies, predictive approaches, fish exclusion and diversion.

The report states that mechanical strikes, pressure changes and hydraulic shear are all likely to cause damage to fish passing through axial flow turbines, under some operating conditions. The author states that studies indicate mortality rates of 2-22% for juvenile salmonids, juvenile shad 40-80%, and adult shad 20% through passage of a range of low head axial turbines. He states that the factors influencing the mortality rate include fish

size, species and turbine operating conditions with such factors as the design head, turbine type, (vertical Kaplan, Bulb or Straflo types), and their runner speed have little influence on mortality rates. The author states that extrapolation from run-of-river (low head) hydro schemes to tidal schemes is unsatisfactory since tidal power generation involves different operating conditions. Solomon points to a dearth of data, apart from experience with the Annapolis tidal power scheme in Canada, where he states, fish passage mortality was not linked to plant operating conditions, and the Rance tidal power station, where no quantitative studies were carried out. The author has therefore developed a predictive approach based on the physical conditions at the turbines.

Solomon states that mechanical collisions are a significant source of fish mortalities, and some collisions are inevitable. He describes the most likely points of collision as the runner blade leading edges and the runner blade tip with a more minor source of collision mortality is likely to be the fixed guide vanes. Mortality rates due to collisions are theoretically predicted as 1.9-3.2% for 15 cm salmon smolts, 5.1-12.1% for 40 cm shad and 12.6-100% for 100 cm adult salmon. These tentative calculations were based on proposed Severn barrage turbine designs, and depend on operating conditions, the author says.

Solomon states that pressure changes can be harmful to fish and under most operating conditions, harmful low pressure could occur, but "under high efficiency operation, these zones are likely to be very limited in extent and few fish would experience them". However, as efficiency falls, says the author, these zones increase in severity and extent, with concomitant deleterious effects on fish. Cavitation, is described as particularly harmful but would usually be avoided by good design for engineering reasons while hydraulic shear might occur under some conditions associated with low efficiency operation, he states.

It is interesting to note this point of impacts associated with conditions of low efficiency, which may be reflected in other renewable energy technologies.

He notes that fish may also pass through the turbines more than once, exposing themselves to the risks several times but Solomon states that more information on this is required.

He suggests that the diversion of fish from turbine passage may be possible by providing a chute or fish pass, at frequent intervals along the barrage for seawards migrants though diversion of fish is more difficult. He concludes that physical screening is not practicable though he describes the use of sound or light as a repellent or attractive stimuli as promising. Surface fish, he notes, are reluctant to dive to submerged passages and additionally, the noise of bulb turbines is he states, inherently repellent, though demersal fish are likely to be more difficult to divert.

The extent of migration delay to salmon smolts or adults is says Solomon, unknown, depending on provision for fish passage; though navigation and homing are thought unlikely to be affected, the barrage would lead to an increase in the level of predation by eg bass or sea birds.

Solomon concludes that operation at either end of the head range and also pumping is likely to be harmful, and that passage of large fish is "likely to lead to considerable mortality".

Dr Solomon makes several recommendations: that more information is sought on fish passage mortality at the Rance barrage, the modelling and prediction of detailed flow

structure in tidal turbines at all operating conditions, and the effects of these conditions on safe fish passage. Also recommended by Solomon for research are aspects of fish migration and behaviour such as movement, diving, sound and light reactions and avoidance behaviour.

This study, analysing the causes of adverse impacts to fish does point to the scope for reducing impacts through more sophisticated design, with regard to fish passes and turbine intakes.

5. Department of Energy

UK Tidal Programme

The report *'Tidal Power from the Severn Estuary'* was carried out by the Severn Barrage Committee for the Department of Energy over a two and a half year period starting in 1978, at a cost of £2.5 million (DEn 1981). It comes in two volumes with 26 pages out of 105 in Vol 1 covering environmental aspects. These are discussed under the headings Water Levels, Flow Patterns, Sedimentation, Impacts on Ports and Shipping, Recreation and Amenity, Industrial Impact, Impact on Sea Defence, Land drainage and Agriculture, Impact on Water Quality in the Estuary, and Impact on the Ecosystem and Nature Conservation.

The introduction states that the Severn Estuary site is one of the world's best sites for tidal energy, being close to major demand centres, and a high capacity electricity supply system. The authors note that many schemes have been proposed over decades, but have never appeared sufficiently economically attractive, though "the realisation that the period of cheap energy is over has lent fresh interest and urgency to the concept".

In fact this report is one of a long series by the Department of Energy on the Severn tidal power scheme and other tidal sites in the UK for example *'Tidal Power from the Severn'*, (STPG 1986), or *'The Severn Barrage Project General Report'* (DEn 1989).

Doubts about future nuclear power station plans are mentioned as another reason for evaluating other potential sources of electricity, such as tidal power. The Severn Barrage Committee was set up in 1978 to advise the Government on the desirability of such a scheme with the major uncertainties to be investigated were the technical feasibility, economic viability and the environmental impact (DEn 1981).

The report devotes considerable space to the choice of site and assessment of different schemes. A summary of the findings states that it is technically feasible to enclose the estuary by a barrage located east of a line drawn from Porlock due north to the Welsh Coast. The main purpose of the barrage would be electricity generation, in contrast with road or rail crossings, or navigation improvement and it would be constructed from concrete caissons with embankments at either end and have locks for shipping. Three schemes were found to be more attractive than any others,

- a) an outer barrage from Minehead to Aberthaw, ebb generation, of 12,000 MW, and 20 TWhr / pa, at a cost of £8.9 M (1980 prices),
- b) an inner barrage from Brean Down to Lavernock Point on the Welsh coast, ebb generation of 7,200 MW, and 13 TWhr / pa, at a cost of £5.6 M, (1980 prices)

c) a staged scheme similar to b, with ebb generation, but with a second dam enclosing Bridgewater Bay, to form a reservoir which would be operated on flood tide. This would be able to generate electricity for 20 hours a day and have a capacity almost as great as the outer barrage.

However, the report states that the Committee considered the outer barrage to have greater engineering risks, greater environmental impacts and lesser economic attractiveness, which would not be compensated by the greater output. It recommended concentration on the inner barrage, as the second stage scheme was found to be economically unattractive.

The report contains an assessment of the economics and an explanation of tides and tidal resonance. This occurs when the estuary length is close to one quarter of the tidal wavelength, causing the amplitude to be increased. It is stated in the report that a barrage would alter the effective estuary length and change the tidal range, which would then affect navigation, land drainage, dispersal of pollutants, sediment patterns and movement, salinity and many other environmental factors.

Impacts on Man and the Environment.

The report states that the environmental changes predicted "either raise questions for which solutions have been suggested, or are not such as to rule out further consideration of a barrage".

The report notes that changes in water levels determine the amount of extractable energy, influence navigation and the drainage of low lying land and could lead to major recreational and amenity benefits above a barrage. The authors state that outside the Inner Barrage, a mean reduction of 11% in tidal range would occur, and for the outer barrage this would be a 20% reduction. for the Staged scheme, a 24% reduction in mean tidal range at the stage I Barrage and a 15% reduction at the stage II barrage.

Advantages cited by the report include recreation which it states would be enhanced due to the lower tidal range and currents and could be a source of employment.

Adverse effects identified in the report would include water quality in the estuary, with rapid dispersion of pollutants by strong tidal currents reduced by the barrage, though the report states that dilution of effluents would be greater due to higher average water levels. "Maintenance of the quality of tidal waters in their present general state would not be technically difficult and could be achieved by introducing more treatment of sewage and industrial wastes, at a cost of £120-230M for plant" the report states. The authors go on to say that the maintenance of present tidal water quality would be a question of choice demanding a policy decision. "Reductions in salinity and turbidity would be inevitable".

Land drainage would require extra pumping for surface run-off water from some areas behind the inner barrage, requiring an investment of £14-19M they continue. The Second Stage barrage scheme would improve land drainage in the Somerset levels though this might be detrimental to nature conservation, says the report.

Other effects included are the sea defences which would be altered since although the risk of salt water flooding low lying land behind the barrage during extreme tides would be reduced, the longer high water might lead to increased wave attack. Sediment transport say the authors would be greatly reduced by the gentler tide regime and much of the

sediment currently moving with each tide would settle. They note that the amount of new sediment entering the estuary is small, though pointing out that the effects on port approach channels still need to be investigated.

On the topic of changed currents the authors state that "the barrage alignment and location of turbines and sluices is such that the alignment and distribution of flood flows remains hardly changed" which illustrates one objective of the design process, -to avoid unnecessary alterations.

The effect on birds through reduction in intertidal banks and reduced salinity is noted and the report states that this might decrease the wading bird and shelduck numbers. But the authors suggest that the change in conditions would lead to new species from bottom feeding and suspension feeding organisms, which could increase the variety of species and total bird population. Expert opinion is divided though, say the authors.

The subject of migratory fish such as salmon should be able to passage upstream through the sluices is discussed, and the report notes that salmon might also be trapped by a second stage basin.

The report describes how a barrage would alter the effective estuary length and change the tidal range, outside the barrage too, which would then affect navigation, land drainage, dispersal of pollutants, sediment patterns and movement, salinity and many other environmental factors.

The report concludes that the choice of barrage site is influenced by many interacting factors, of which the energy output and cost appear to be the most important. The two stage barrage, the report states, could have significant environmental impacts due to there being only one tide per day with a high water stand lasting all night, which could have severe effects on drainage, sea defence, ecosystem including birds.

The impacts from tidal power schemes are to a large extent interrelated, say the authors requiring long term studies which involve a large number of uncertainties. The conclusions reached are therefore inevitably less certain than the technical and economic studies, they state. They comment that "the importance and lack of firm knowledge of fine sediment behaviour was shown up and the Severn Tidal Power Group consider it the most uncertain of the major factors determining the ecology of the estuary affected by the barrage".

The need for engineering and non engineering studies to be interactive and scheduled to be compatible, is noted together with the need for sufficient information to assemble impact assessments. The need to regard 'impact' as open to variation from sensitive engineering design and activity, and the need to seek environmental gain while minimising environmental loss is pointed out.

The growing maturity of the studies and design process for tidal barrages is noted by the report. The authors state that "the many environmental studies initiated by the Severn Barrage Committee and others provide increasing evidence on which to reach instructive decisions about the likely minimum impact of each barrage scheme". More scientific information was now available, they state, and this has lead to changed perceptions of the significance of specific issues and so construction and operating details have been varied to offset environmental effects.

One example of the changes in design of the Severn barrage is a more porous barrage, with a larger number of turbines and sluices which reduces changes in currents and impedance.

There is a dearth of literature on the only existing full scale tidal plant in the world, and very few studies have been carried out on it, and no quantitative studies. Below two papers covering impacts from the Rance barrage are reviewed.

6. Rance Barrage Experience

This paper, *'Lessons from La Rance'*, includes some reference to environmental and ecological issues on the Rance Tidal Power Barrage, the world's only full scale tidal energy plant (IWPDC 1987). The author describes how in 1960, La Rance's ecology had not been particularly studied, but it was in 1987, "the source of a succession of constraints, restrictions, complaints and problems from fishermen, instead of praise for being a major tourist attraction" according to Pierre Hillairet of EDF, the French Electricity Company. Oyster farmers the author relates complained that 'it was not like it used to be', and amateur sailors said that the channels are no longer charted, while local inhabitants said that the scenery had been changed and raised drawbridges blocked the road. This somewhat anecdotal description of public attitudes does illustrate that the public may not necessarily welcome tidal barrages.

M.Retiere, director of the maritime laboratory of the Dinard Natural History Museum is then quoted giving a more detailed account of the ecological effects. He acknowledged that the Rance ecosystem had been profoundly changed by the barrage, but denied it had been for the worse. Environmental impact had been amplified by the method of construction chosen, a coffer dam had been constructed when the dam was built, and this cut off the estuary from the sea for three years. Salinity fluctuations, heavy sedimentation, and accumulation of organic matter had ensued which led to the almost complete disappearance of marine flora and fauna, he said. The civil engineers proposing tidal schemes have certainly noted this high impact from construction of the Rance barrage, since no current plans involve such drastic cutting off from the sea, usually employing instead, caissons floated in.

Retiere states that after inauguration, the tides returned but in a changed rhythm and range; the intertidal area was much reduced, and strong currents from sluicing and turbine ducts had changed the shape of the estuary.

However, he stated, aquatic life has returned and a new and different biological equilibrium had been achieved 10 years after the tidal flow returned. Retiere said that the estuary once again is a nursery to underwater creatures, and a considerable habitat for birds. However, the author continues, the biological equilibrium depends on the regularity of the power station's operation, and irregularities can have drastic effects on populations. For example he cites 1983, when an 80 % decline in plaice population occurred due to irregular operation. Retiere stressed that the lessons of the Rance were not necessarily applicable to other tidal power sites.

This paper '*Energie Maremotrice: Aspects lies a l'environnement aquatique*' is a more detailed account of the studies and environmental impacts of the Rance tidal power plant in the French language (Massonnet et al 1984). A nature protection law, introduced in 1976 in France, requiring environmental impact studies was the starting point for studies of environmental acceptability. These regulations required better information, for the public, elected officials, and institutions to provide a deeper understanding of the problems and solutions. The EDF, the authors state, Electricity de France, is particularly sensitive to environmental problems, with mutual agreements between EDF and the Departments of the Environment, Industry, and Research to carry out environmental work with a budget of 1400M F in 1982.

The aim of these studies on the Rance tidal power plant which had been in service for 15 years, the author states, was to discover the environmental consequences of construction and operation of the plant, and the studies necessary for a large project.

Rance Barrage Construction impacts

The authors state that apart from flushing for cleansing, the estuary was cut off from the open sea for three years, from 1963-1966. They describe how inside the basin, the tides and the important fluctuations of water salinity were suppressed during this period and much sedimentation together with a big accumulation of organic matter occurred. These novel conditions the authors state, led to the almost total disappearance of marine flora and fauna, apart from certain very hardy species such as mussels or certain mud inhabitants which flourished.

Operation of the Plant

Massonnet et al state that the main effect is the modified rhythm and the reduced amplitude of the tide. They state that transformation from strong tides in a basin to small tidal range, results in reduction of the wetted intertidal area and note that the strong currents from turbines and sluices have to some extent altered the morphology of the estuary. In the vicinity of the barrage, certain beds have been eroded and some sand banks displaced the authors state.

This erosion from the turbines and sluices has been noted by the designers of later schemes and sluices and turbines are generally more evenly spread along later schemes.

Massonnet et al describe how in the northern part of the basin some large sediments have more or less disturbed the gravel beds covering the river bed, by disturbing the remnants of existing deposits and not replenishing them. In contrast, they note, the long slack periods have encouraged the deposition of fine particles of marine origin in the creeks, most evident during the first few years of plant operation.

Sedimentation is obviously a considerable concern of designers of barrages.

Biological Consequences

However, the authors stress that the stability of the new distribution order of the organisms is evidently dependent on the regularity of the operational rhythm of the tidal plant.

They note that the wealth of fish population of the Rance is greater than for example that of the Tamar estuary in England or of the Mont St Michel Bay, citing it as evidence that

the barrage is not entirely hostile to the local fauna. The Rance basin they state, does not appear to show significant differences in density, distribution, or biology, for many species. They state that it must be recognised that biological equilibrium depends on the notion of regular operation of the functioning of the (tidal power) plant. In fact some irregular variations of levels, upper and lower of the basin could have drastic biological repercussions : such as those in the previous June which precipitated an 80% decline in density of young plaice population. Finally it needs to be emphasised that despite the reduction of the intertidal zone, the Rance constitutes a not inhospitable site for water fauna wintering

This paper about the pilot Russian tidal scheme is included in this review since it describes other effects from tidal plants, and also confirms some of the 'lessons' from the Rance.

7. Kislogubsk Tidal Plant

In a paper about the 400kW Russian tidal power station on the Gulf of Mezen on the North coast of the White Sea, at Kislaya Guba titled '*Investigations at the Kislogubsk Tidal Power Station*', the authors concentrate mainly on the construction, which used the then novel method of floating in prefabricated concrete caissons (Usachev 1989). Constructed in 1969, the authors say that this method, "marked a turning point in the solution of the problem of utilizing tidal energy". Which might well be confirmed by the severe impacts from former methods of construction at the Rance. Although most of the paper is given over to construction, dynamic loading, and water seepage, there is a section dealing with environmental impacts and considerable coverage of anti fouling techniques. Fouling reaches 25 kg / m² and leads to clogging of the underwater conduits and a decrease in the generation of electricity. The authors cite the Rance tidal power station which they state, shuts down annually so that one ton of fouling biomass can be removed from each of the 24 units. At Kislogubsk tidal power station, they state that biocidal additives are incorporated in special concrete compositions. The authors state that nonfouling concretes last ten years while coatings last only 2-4 years therefore a continuous system of nonfouling was developed using chlorine extracted from sea water by means of a pump and electrolysis. They state that this deters the larvae which foul the conduit walls, and is used only during the breeding season. The authors say that the system is ecologically clean. However, Langford (1983) discusses environmental impacts from anti fouling substances including chlorine and considers that they can have a big impact in themselves.

On the subject of ecological issues, the authors say that the ecological cleanness of Tidal Power Stations in the form of single basin ebb and flow generation is not in doubt. However, they remark that at Kislogubsk the "violation" of the original scheme to one shift only operation with long stops, resulted in "biological asphyxiation" or eutrophication. Since then, they relate how constant three shift operation has been resumed so that the maximum (49%) water exchange with the sea was achieved, and after this the basin began to recover.

This confirms the experience from the Rance that the new altered regime is still crucial to the ecology within the basin, and interruption or variation in it such as would be involved with load following or peaking operation are liable to lead to very big impacts.

They describe the area as favoured by very clean non polluted conditions, being far from industrialisation. They comment that the ecological investigations will need to be made over a long enough period to span peak operation in the winter and one way operation while the ecological need for the design regime to be fulfilled is stressed.

The next paper to be reviewed here concerns the Annapolis tidal scheme which is the only other existing scheme aside from the micro scale plants in China.

8. Annapolis Tidal Power Plant

This paper '*Assessing the Environmental Impact of the Annapolis Tidal Power Project*' describes the processes and some of the results of investigations (Tidmarsh 1984). The Annapolis tidal power scheme is described by Tidmarsh as a small, 18MW pilot plant based on a Straflo type turbine plus generator unit and this was built into a pre existing barrage, built for drainage purposes. The Annapolis river estuary, in Nova Scotia in Canada, flows into the large Bay of Fundy area where some of the greatest tidal ranges in the world are found. The purpose of the scheme the author states was to test the concept of the cheaper type of Straflo turbine. He states that the site was selected because the barrage was already in place, possessed adequate sluicing capacity and the impounded basin provided adequate storage capacity with sufficient tidal range for a proper test. He states that construction started in 1980, using a 7.6 m diameter runner with four fixed blades, a normal output of 17.8 MW, operating on a design head of 5.5 m, maximum 7.11 m, ebb flow only. He notes that the project was undertaken on the condition that the environmental impact would be assessed and this started in 1979, based primarily on information available in the literature and data from unpublished sources.

The author states that the site is unusual because the impounded basin is not in a natural state with since enclosure for drainage purposes, had reduced the tidal range from 6.3 m mean to 0.4 m mean. He states that the barrage created a body of standing water changing the basin from a well mixed system with a high flushing rate to a stratified water body with only limited exchange with the sea. "The ecological and physical effects of the barrage were never assessed quantitatively, and so the changes remain uncertain, although a cooling of the microclimate upstream and some changes in the anadromous fish populations have been attributed to its presence" Tidmarsh states.

This use of a pre existing barrage site could in fact become relatively common with economic advantages and gives this study greater relevance.

The author states that the assessment was therefore confined to barrage redevelopment, and operating the power plant and secondly to the effects of increasing the maximum water levels and causing greater water level fluctuations in the basin. He describes how under the heading of barrage redevelopment, and power plant operations, four areas of potential concern were identified: suspended sediment loading, bank erosion and bottom scour and fish passage.

Tidmarsh states that bank erosion and bottom scour was feared due to the location of intake, tailrace and sluices, so bank protection was required. He notes though that the high water velocities of 2.4 m / sec through tailraces and up to 6.3 m /s through sluices were still however, a reduction on the previous situation.

This avoidance of faster currents than previously existed is characteristic of tidal design, since such changed conditions usually spell greater impacts.

Tidmarsh states that fish passage would be difficult to assess but a new pass was still required by the Fisheries Department. However, he states that the Straflo turbine has advantages over other designs, and due to the low heads involved, the 80-90% efficiency of the Straflo turbine which minimises shearing forces, the large size draft tube and relatively slow turbine speed with small cavitation, it was expected that fish mortality would be small, apart from larger fish. For the latter, eg the adult striped bass, 1 m in length, he states that a 10% mortality rate was expected.

Other worries had included flood flow management Tidmarsh states, but the sluicing capacity would be sufficient to prevent any flooding upstream with good water level management. Also basin water level management concerns had been voiced since the water level was raised by about 1 m, he states, with Flooding a concern, but this could only be caused by river freshwater inflows. Tidmarsh states that saltwater incursion was also assessed for detrimental effects but there is little risk of incursion. He notes that bank erosion has accelerated since the barrage was built, and after project completion, there could be further erosion in places, though in other areas erosion could be retarded. Remedial bank strengthening works could be required.

Such concerns are typical of tidal schemes, whether of the Severn, or elsewhere, though individual site characteristics can accentuate one factor, or diminish others.

In conclusion, Tidmarsh states that the most important environmental impact issue is fish passage and while other issues were amenable to mitigation, fish passage through the turbine could not be resolved to the satisfaction of all the parties. He says that only experience of operation of the project will reveal the impact.

This paper '*Environmental Consequences and Ameliorative Measures of The Annapolis Tidal Power Project*' covers similar ground to the one cited above, but in greater detail. and the process of the environmental impact assessment is described by the authors for the Annapolis Tidal Power Project (Daborn et al 1984). The authors describe how it can be employed as

- i) a sieve resulting in a yes or no decision on a scheme go-ahead, and
- ii) an iterative design development & modification process.

The process comprised assessment of the preliminary design's effects and modifications until approval was given in principle, with provisos for final design modification, until the licensing authority was satisfied and construction permits issued. Then further assessment was carried out after construction.

As a retrospective on the environmental assessment process, the authors state that this representation of the process is both idealised and simplistic, and that it is unlikely that

such a mechanism could function effectively on a larger project with wider environmental effects or involving more interest groups.

The authors state that examination of this development emphasises one of the most important features of the environmental assessment process; that is the communication between the developers, designers and engineers on the one hand, and on the other, those studying the environmental processes that will be considered by the licensing authorities. Daborn et al state that a large body of expertise was available to the project, from the Fundy Environmental Studies Committee, a voluntary association of scientists engineers and power companies. In the authors view, "it is not often clearly perceived that engineering projects possess a great deal of flexibility at early stages of their development." They remark that later on, as plans are refined, flexibility declines. The authors state that public misconception of this, may cause reactions to initial proposals as though they were inflexible and unable to accommodate environmental imperatives. Therefore they believe it is important to include environmental scientists into the discussion as early as possible, particularly in view of long lead times for assessment of little studied natural systems.

9. Bay of Fundy Schemes

This paper *'Integration of Ecological and Engineering Aspects in Planning Large scale Tidal Power development in the Bay of Fundy Canada'* describes the history of tidal power projects and the development of environmental studies of the world's largest potential tidal power site by Gordon of the Marine Ecology Laboratory, Bedford Institute of Oceanography, Dartmouth, Canada (Gordon 1984).

Gordon describes tides in the Bay of Fundy in Canada which are some of the largest in the world, at 10-12m mean range and up to 16m at certain times and places. Schemes to harness these tides in several smaller bays have he states, been proposed for over sixty years. The Annapolis Royal scheme went ahead in 1980 as a pilot scheme for a large project in the upper part of the bay which could have a capacity of 4000MW. Gordon states that over half of the bay is intertidal sandflats, mudflats and saltmarshes. There are few local centres of population, Moncton at 60,000 is the largest settlement, and there is little pollution in the area.

Strong currents of up to 4m sec^{-1} occur, and low tide water depths are less than 20m.

The upper reaches of the estuary are very turbid, and because of the high turbidity, light is the most important limiting factor of primary biological production from photosynthesis. Total annual average primary production estimates are relatively low for temperate estuaries. Fish and birds are some of the top predators, and the Bay of Fundy is internationally important for them. The author states that the upper Fundy Bay has much in common with the Severn estuary, in the UK. Gordon states that environmental knowledge is rapidly accumulating stimulated by tidal energy proposals, especially since 1970. Studies on physical, sedimentological, chemical and biological aspects have been carried out, and he believes the general environmental properties are now reasonably well understood.

Gordon relates that the initial proposals from about 1920 onwards were for an international tidal power scheme in Passamaquoddy in Canada and Cobscook in the USA involving two basins.

Environmental impacts were judged to be local and minor, he says and the results of studies were not used in developing the engineering designs as the scheme was dropped again on economic grounds. However, a tradition of contact between environmentalists and engineers began.

He states that three sites were identified as technically feasible, Shepody Bay, Cumberland Basin and Cobequid Bay, but turned down in 1969 as not yet economically viable.

By the early 1970's, the oil price rise had changed the economics of tidal power and the governments of Canada, New Brunswick and Nova Scotia created the Bay of Fundy Tidal Power Review Board.

A group of engineers and scientists was formed to investigate environmental issues, identifying the impacts from construction and operation of a tidal power plant, ranking their importance, and determining the requirements for a full environmental impact assessment.

In 1977, the Bay of Fundy, Tidal Power Review Board (cit. in Gordon 1984), produced a tentative priority ranking of environmental issues in terms of natural resources:

High	Agriculture, Drainage and Flooding
Moderate	Birds, Anadromous Fish
Low	Other fisheries, Recreation, Minerals, Navigation

It was concluded that none of the potential environmental impacts were serious enough to preclude development and that development of the Cumberland Basin site had the least impact on the environment.

Tidal amplitudes throughout the Bay of Fundy and Gulf of Maine would be changed by the Cobequid Bay scheme, with increases of 15cm predicted as far away as Boston. This has been the cause of some concern in the USA and requires further quantification.

"No major chemical impacts are anticipated at the present time" Gordon states.

Ecological impacts are affected by the reduced turbidity, as suspended silt concentrations decrease, due to lower energy levels. Reduced tidal range will reduce the intertidal area and so the primary production of benthic microalgae and saltmarshes is predicted to drop. This lowering of productivity however, is likely to be offset by increased phytoplankton production resulting from greater light penetration.

The Cobequid Bay site was now considered preferable to Cumberland Basin due to its lower productivity at all trophic levels, reversing the original 1977 assessment. However, although ecological knowledge had increased as a result of the studies, the wider ecological implications of tidal schemes eg to fisheries to the outer Bay and Gulf of Maine were not well understood.

The results of impact studies will influence the final design and operation procedure of a tidal power project and also the decision whether or not to build. Site selection, single or double effect operation, construction method, and operation procedures such as limits to shutting down the barrage will also be influenced by environmental impact studies. Gordon cites the positioning of sluices and turbines as an example of integration of

environmental knowledge into engineering design to mitigate negative effects and augment positive ones. He adds that the regular operating routine could be interrupted in order to flood salt marsh areas, or operate on flood generation at times if this might mitigate distinct environmental impacts.

However, as noted interrupting the tidal regime has severe ecological impacts, and so any such operation should be carried out at regular intervals. Positioning of sluices and turbines is, as noted important for avoiding extra impacts.

10. Conclusion

Although there is an extensive literature on tidal energy, and on particular schemes, only four tidal schemes have actually been built and only one has been full size and so the confirmation of expected environmental impacts is limited.

Tidal power schemes as can be seen from a view of the literature have always employed barrages to increase the head and power output. This causes very marked changes in the water levels, currents and energy levels which can considerably affect the natural processes, the water quality, the flora and fauna.

Most of the effects of tidal energy impact upon the animate and inanimate sectors of the environment rather than the human domain, although there are some effects to land. It is interesting to note that impact assessment issues such as land use hardly feature, - unsurprisingly since the barrage occupies estuary space and not land.

No two estuaries are the same either in their tidal conditions or in the life they support, though they will all have features in common. Different designs and operation regimes do have a considerable effect on the type and degree of impact caused. Not all of the impacts appear to be detrimental.

However, the changes that tidal energy schemes impose on the tidal regime, do still need to stabilise for flora and fauna to adjust to the new conditions. Any variation in even the altered regime will have a big impact. Out of course operational patterns eg changing the ebb only flow to two way generation, for load following or closing of the barrage for maintenance would impact very severely on the ecology. Evidence for this can be seen from the experience of the Rance and the Kislogubsk tidal plants.

The influence of the environmental impact studies does, in the case of tidal energy appear to be quite significant. The technology and individual designs have been modified considerably in the light of environmental needs. Eg the Severn barrage scheme envisages a much more porous barrage than the Rance scheme used, with more dispersed turbine units thus minimising scouring and changes to existing currents. Economic interests still remain the dominant influence on tidal schemes. For instance high water pumping is still incorporated for economic reasons even though its impact on fish may be considerable. The non implementation of the Severn scheme is due mainly to its poor rate of return rather than the vociferous opposition aroused by some conservation bodies. The impact of tidal stream technology currently being developed seems likely to be low, but there is as yet little data available (ETSU 1993).

Table 7 Summarising Impacts from Tidal Energy

Barrage	<u>Tidal</u>	<u>Tidal Stream</u>
Semi Marine		
Env. Created		
Small /no land use		no land use
Reduced Tidal Range		little effect on Tidal range
Few/no incompatibs.		No incompatibilities
Reduced/ raised		Small water speed reduction.
Wildlife Change		Small Wildlife effect
Siltation Possible		No siltation
Changed Species		Little change.
Water table effects		No effects.
Drainage Effects		" "
Tidal changes		Little change
downstream		
Poss. increased erosion		
Fish migration barrier		Insignificant. obstacle
Fish turbine strikes		Less
Fish pressure damage		Small effect
Flood protection+		
Shipping Hazard		

Chapter 7

Solar, Wave and Ocean Thermal Energy

In this chapter some of the literature of the less exploited renewable energy sources is reviewed; solar energy, wave and ocean thermal energy.

Solar

Introduction

Solar Energy technologies harness the sun's radiation either directly intercepting the electromagnetic radiation or indirectly via thermal conversion. Potentially, the resource is the largest of all of the renewable energy sources with 1.2×10^{15} W of solar energy absorbed on earth (Twidell & Weir 1986). In practice though, at the present time, solar energy technology, although promising and to some extent proven, is barely commercial for ordinary power generation. However, niche markets continue to expand (Stone 1989), the technical development of solar energy progresses and the cost per kW of installed capacity continues to fall.

The main technologies are flat plate Solar Thermal for water heating, Solar Concentrator, and Solar Photovoltaic for electrical energy and passive solar for space heating in buildings. Various permutations are employed, for example, concentrators plus photovoltaic cells, or parabolic reflector concentrators plus a heat transfer and energy conversion unit, or heliostat reflectors focussing on a central receiver system with a thermal energy converter in the 'power tower' type of plant. These variations of the technology result in quite different plant and equipment on the ground and hence different impacts.

Some literature exists on the environmental impacts of solar energy, a selection of which is reviewed below.

In a paper on the current status and future prospects of solar energy, '*Solar Energy, Current status and future prospects*', Charters quotes the average energy value for solar radiation as 5-6kWh / m² / day in a good solar climate, eg Australia, and in a poor solar climate eg N. Europe 2-3kWh / m² / day (Charters 1991). He goes on to state that summer to winter radiation levels may vary by a factor of 2 to 1, with a greater variation in poorer climates.

Land Area Required

On the subject of the use of land area, he calculates that 1km² will provide 500 MWh electricity output per day, assuming a 10% efficiency rate.

Charters (1991) writes that it is a fallacy that (passive) solar housing needs to consume more land area than conventional housing, with 30-50 houses / ha density possible with a solar efficient design in the US, compared to 10 houses / ha density of a typical suburb there (Flavin & Lenssen 1990).

For electricity generation, it has been calculated that solar thermal electric, and solar photovoltaic require the same order of land use, 30000-35000m² / GWh over 30 years, (Flavin & Lenssen 1990) as coal fired electric generation, if full account is taken of the

mining operation. Charters makes the point that marginal or desert land can often be employed for solar energy use.

Toxic Wastes from Manufacturing

On the subject of toxic wastes from the manufacture or disposal of photovoltaic cells, Charters considers that this may become a problem if the technology adopts large scale use of multi layered cells using the 'exotic' materials such as gallium arsenide or cadmium sulphide. However, he considers that the current use of silicon solar cells does not pose very many environmental constraints on production.

Pimental *et al* also state that the major environmental problem associated with photovoltaics is the possible use of toxic chemicals such as cadmium sulphide and gallium arsenide in manufacture citing Holdren (1980).

Wilenitz *et al* published a paper on the costs of controlling emissions from manufacture of photovoltaic cells in 1985 titled 'Costs of Controlling Environmental Emissions from the Manufacture of Silicon Dendritic Web Photovoltaic Cells' (Wilenitz *et al* 1985). They state that though environmental costs are currently small in comparison with total silicon photovoltaic cell production costs, they will however be a greater proportion when production costs fall by 5 or 10 times, as they are projected to.

This work was carried out as part of the US Department of Energy studies into material and process alternatives, as part of the DOE National Photovoltaic Program. The authors state that silicon dendritic web technology was selected because the data was available and the study investigated costs of emissions for a 10 MW_p (peak) facility. Production, they state, involves eleven steps and can result in air pollution, liquid discharges, and solid wastes. The regulations applying to photovoltaic cell production were assumed by the authors to be the same as those applying to semi conductor manufacturing industry. Acidity, fluoride and toxic organics are the main pollutant parameters of concern, the authors state. They describe how vapour emissions which do not require treatment are vented to the atmosphere while fluorinic vapour emissions are scrubbed with alkaline water, and can be highly corrosive eg silicon tetrafluoride. Wilenitz *et al* state that some of the liquid wastes can be sent away for recovery eg the hydrofluoric acid used for etching, or the isopropanol can be used for washing. The fluorinic wash however they say, needs to be treated and this represents the biggest cost. Solid wastes, such as impure silicon, say the authors, can be safely disposed at secure or municipal landfill sites.

The authors conclude "that the only environmental pollutants discharged in large quantities from a silicon dendritic web photovoltaic cell manufacturing facility are fluorine compounds". They state that the costs of controlling emissions range from 1.4c W_p⁻¹ for an integrated plant to 2.8c W_p⁻¹ for a disaggregated plant. In 1985 the authors say the production cost was \$ 5 W_p⁻¹, and that capital costs for emissions control equipment ranged from 50-55% for the integrated plant and 36-40% for the disaggregated plant. They point out that the incremental costs of controlling emissions are 15% of total costs which is not very significant, but would be of greater importance were the production price, the price per Watt, to fall significantly.

Resources Consumed in Manufacture

Pimental et al, in an interesting paper, '*Solar Energy , Land and Biota*' consider whether the amount of land, materials energy and other inputs required for renewable energy technologies will limit their exploitation (Pimentel et al. 1984). The authors say that though solar energy technologies (ie all renewables) offer a secure renewable energy source, because solar energy is diffuse, it must be collected and concentrated to be usable in large scale applications. They say that since some solar energy technologies require large amounts of materials, energy, land, and other resources, this may limit the extent to which solar energy can replace fossil and other sources.

They cite the land use for construction of a Solar Thermal Central Receiver plant as 800ha per 1 billion kWh / yr of electricity assuming a 17.4% peak efficiency and 6 hours storage. This calculation takes account of the steel, concrete, other materials required to construct and operate the plant. The Energy Input to Energy Output Ratio is cited as 1:19. For solar photovoltaic energy, 600 ha per 1 billion kWh / yr is quoted at an Energy Input to Output ratio of 1:17, assuming a 15% peak efficiency and 300kWh / m² (OTA 1979).

At least half of the photovoltaic cells could however, the authors point out, be mounted on the rooves of homes and industrial and buildings and would therefore require smaller amounts of land. (Milne et al 1979).

While photovoltaic cells might be mounted on rooves with little effect or impact, Central Solar Receiver plants may have other impacts such as local atmospheric effects, and the paper reviewed below assesses possible effects.

Central Solar Receiver Plant Effects on Atmospheric Conditions

Chandrakant et al have studied possible changes in ambient atmospheric conditions caused by a large solar central receiver power plant in the Barstow area of California. (Chandrakant et al 1981).

This specialised paper describes the numerical modelling of potential local and regional atmospheric changes for a variety of solar plant configurations. The authors state that a 100MW_e solar central receiver plant would require approximately 1km² of mirror area, whose ground cover ratio could vary between 0.25-0.5. in order to avoid shading of mirrors by each other. They state that typical mirror areas of single heliostats vary from about 30 m² to 40 m² . "Solar radiation is the principal forcing function of weather and 80% of this radiation is transformed at the earth's surface into other forms of energy" they note. Changing the characteristics of the surface can cause changes in the surface energy balance, they state, and non mirrored areas have a lower albedo (fraction of incident energy reflected). They explain that this results in surface temperature and outgoing long wave radiation being altered. Heat diffusivities of mirrored and non mirrored areas can differ by as much as an order of magnitude they state. Due to compacting of the soil, they note that transfer and storing of incoming energy in the deeper layers of the soil can occur. The authors state that impermeable surfaces and rapid run off affect latent heat while the effect of the waste heat from the plant can be quite important. The authors hypothesise that these changes may alter wind, temperature, and specific humidity, and this may result in secondary effects such as surface energy balance, cloudiness, or precipitation.

The study modelled a plant extending over a distance of 2.4km with the cooling tower located in various different positions, either on the upwind or downwind edge of the plant. In addition the model tested the effects of either a 'wet' cooling tower with 80% latent heat 20% sensible, or a dry one with 100% sensible heat. Typical weather conditions were fed into the model which however, being only two dimensional could not model wind flow around the mountain. They describe three simulations which were carried out; one with no solar power plant, a second with the solar power plant with an upwind wet natural draft cooling tower, showed the formation of a large cloud with humidity and wind flow patterns characteristic of those of a thunderstorm. The authors state that "the result of this scenario shows that under certain atmospheric conditions, the changes in surface characteristics together with waste heat associated with a 100MW_e solar thermal power plant have the potential to cause formations of clouds or rain at and in the vicinity of the solar power plant." They state that when a simulation with the wet cooling tower at the downwind edge, was modelled, the intensity of the atmospheric perturbation was reduced considerably and the only cloud to have formed developed in response to the mountain effect. Chandrkant et al state that a simulation using a dry cooling tower also reduced atmospheric perturbation significantly, and hence cloudiness.

These findings are typical for cooling towers which can have micro climatic effects. Studies have been carried out on the effects of cooling towers for thermal plants, coal, oil or nuclear, and Langford (1983) discusses this issue.

The higher energy intensities of such centralised solar energy converters may be responsible for the higher level of environmental impacts, and if so then the orbiting solar satellite system with high energy intensities should also exhibit high levels of impact.

Orbiting Solar Satellites

Some of the literature from the late '70's and '80's covers the more exotic subject of environmental impacts from orbiting solar satellite power stations which beam back to earth the energy intercepted by microwave. Although this technology is very much still at the conceptual stage, and not even a prototype satellite has been constructed, Satellite Power Systems (SPS) have been studied by the US Department of Energy '*Environmental Problems with Microwave Power Transfer from Satellite to Ground*' (US DOE 1978).

This paper describes how such a satellite would be stationed in geostationary orbit and collect solar energy by means of photovoltaic panels. The energy would be converted into microwaves of 2.45GHz frequency, and transmitted via extremely directive transmitting antennas to large receiving antennas on the ground. The advantages such a system would be that the energy levels of solar radiation would be much greater than on the ground, and would be available for a longer number of hours per day.

The authors state that power transmissions for SPS ... "will expose the general population and the environment to low levels of microwave radiation." There is also the potential for high levels of exposure from eg birds flying over the antennae or workers at each antenna site.

They note that although there is a limited literature on exposure to short term high level exposure, little is available on low level exposure and none on ecological effects.

The possible ecological effects from SPS microwaves are divided in the paper into those from high power density, beamed down from the satellite to receivers and low power density from scattered beam radiation. High power density microwaves, eg $\sim 23 \text{ mW / cm}^2$, the authors state, might affect the behaviour, mortality, navigation and reproduction of airborne biota, while low microwave power density, $\leq \sim 1 \text{ mW / cm}^2$, might affect natural ecosystems via plant productivity, population and community changes of plants, vertebrates, and invertebrates, and also might affect agricultural ecosystems through crop and domestic animal productivity.

Possible human health effects resulting from chronic exposure are listed as including interference to biological cycles, genetic and foetal development, immune systems and delayed effects and cancers might result. They state that intermittent exposure may result in glandular effects, cataracts, delayed effects and cancers.

The authors describe the effects on the environment, including the possibility of climatological and heating effects in the lower atmosphere with a possibility of the natural atmospheric condition causing a variation in refractive index. This may, they state, lead to beam wandering, spreading and doppler shift, or beam control instability, and this in turn may cause some ground heating and soil moisture evaporation changes resulting in some weather and climate modification, which might also be caused by waste heat from the ground antenna. In addition they state that the ground antenna could have some effect on the incidence of electrical storms in the area.

Lastly the authors state that the size of an SPS is large enough for there to be a possibility of heating the earth's ionosphere which would result in significant performance changes in telecommunications systems and satellite to ground systems.

Throughout, the authors concede the lack of substantive literature. They conclude that this preliminary assessment demonstrates the operational degradation that would occur within 100km of the ground receiving site, and that "the basic functional and operational impacts of SPS are of such a magnitude that in many instances they represent unacceptable or impossible compromises and biases to proper test and evaluate exercises performed by the facilities involved."

Similar effects are discussed by Glaser in a paper 'Environmental Implications of the Solar Satellite Concept', (Glaser 1984).

Conclusions

The above literature reviews several different types of solar energy technology which have very different levels of environmental impact. Solar Passive use would appear to have almost no environmental impacts. Solar photovoltaic technology has relatively innocuous effects when mounted on buildings, for example Baumann lists visual intrusion, and occupational accidents in addition to those described above (Baumann 1994). The low energy flux however, necessitates considerable use of materials, and manufacture of these constitutes the main impact especially if exotic materials are employed. Solar thermal water heating devices similarly requires much material resulting in manufacturing impacts. For other solar technologies, both considerable material use is required and the concentration required can result in other impacts, depending on the scale, and efficiency as well as the form the energy is converted into. It would appear therefore that impacts are related in some way to the energy densities.

The effects impact largely on the landscape and the human environment, except where marginal land is used or for exotic solar satellite technology. Expected impacts from the latter technology have caused work on it to be abandoned. Land use may also preclude use of central solar receiver technology, though the very high solar fluxes required would largely be found in deserts and marginal land. Environmental impacts range from being insignificant to very significant for different solar energy technologies.

Table 8 Summary of Impacts from Solar Energy

Landuse / use of space

Incompatibilities

Planning

Noise

Visual

Safety

Glare

Wildlife

Wave Energy

Introduction

Wave energy has not yet been developed beyond the prototype stage and there are only a very few wave energy plants in operation in the world. The technology for harnessing the waves comes in a variety of forms, with a basic division being between the onshore and the offshore devices and between floating devices and devices fixed on the sea bed. The wave resource offshore is considerably greater, but conditions are more severe and a converter must survive storms. Development of wave energy has been carried out with onshore devices usually employing oscillating water column designs, with air compressed in the column driving a generator via a Wells turbine. One such small prototype has been constructed on the island of Islay in W. Scotland.

Another design, known as the Tapchan, employs a tapering channel to raise the wave height, so that the wave spills over a cill into a reservoir. The reservoir level is higher than sea level and this head provides potential energy for the water to flow back steadily via a turbine and generator. One such scheme has been constructed in Norway.

As yet viable offshore devices have not even been developed to full size prototypes and most remain as untested and untried designs. However, wave energy devices have been proven to work and could be developed and exploited in the future.

The wave energy resource is considerable having been calculated at about 50GW for Europe in seven countries by Mollison, (1989) with the UK and Ireland having about 12GW each.

There is only a small literature on environmental impacts of wave energy most of which concerns the putative UK 2 GW Wave Energy Research and Development programme of the late 1970's. Some of this is reviewed below.

A report by the UK Department of Energy in 1978, 'Wave Energy', which reviews the government's wave energy R & D programme includes a section on possible environmental impacts (ETSU 42 1979). Nine pages out of a total of 89 cover environmental and social aspects. The authors state that the development of the technology has not yet reached the stage where firm conclusions can be drawn but the possible environmental impacts have been analysed so that areas can be selected for further study. They state that "no environmental effect has emerged which would raise major doubts about the ultimate acceptability of floating wave generating stations." The introduction, by F.J. Clarke Chairman of the Wave Energy Steering Committee, describes wave energy rather negatively, as a diffuse resource requiring large areas of device having to face the sea, over long stretches of coastline, if a nationally appreciable amount of power is to be generated.

Initially the report considers environmental aspects of a long length of large wave energy converters off the coast of the Outer Hebrides. The possible effects of converters on the local shore line through changes in the wave climate were considered, together with the possible effects on fisheries, shipping navigation and the social and economic effects on local communities. However, the impacts are likely to be related to the proportion of energy intercepted, and the numbers of wave energy converters deployed. Since little indication is given of the fraction of the wave front intercepted, the conclusions can only be very general.

Wave Climate and the Shore Line

The important issue of the effects of interception of wave energy on the beach profile and shape is discussed. The report states that since wave energy converters are designed to extract some of the energy of waves, over part of the wave spectrum, the extent and band width will depend on the converter design. "The environmentalist will be concerned with the amount of energy which continues to be transmitted by the waves because it is that which may influence the physiography and ecology of the neighbouring shoreline." the report states.

The authors describe the analysis by the Hydraulics Research Station of the height, direction and frequency of waves transmitted beyond the converter line. The diffraction from gaps between converters, re-injection of energy into the wave spectrum from the wind, and the sea bottom shape were also studied.

The report states that one model predicted that with converters of 20m depth operating in a storm of 15m/s blowing over a distance of 400km for 24 hours, wave height would be reduced from 5.9m to 4.6m and the period increased from 8.4 s to 9.0 s.

The most noticeable effects on the shoreline would occur during periods of medium wave activity, with high reflection and conversion rates giving significantly lower energy in transmitted waves, the authors state. The effect on beaches of S.Uist, Benbecula and N. Uist was predicted to reduce the difference between summer and winter beach profiles. In summer they state, the sand / shingle accretes and moves up the beach, while in winter it is

eroded and deposited further seaward. They add that if the converters were to be located less than 30km offshore, then the steepness of the waves might be reduced and the beaches might accrete due to less erosion from winter storms. The authors conclude that the effects of converters located off the coasts are more likely to be beneficial than detrimental for beaches. However, they caution that this would not necessarily apply to other coasts, and that each site would have to be considered in detail. In a final point, they state that were the converter to be mounted on the sea bed much closer to the shore, as in some designs, the environmental consequences would be much more substantial and would depend on the local conditions and geography. Such converters would they state constitute a permanent and perhaps undesirable change to the sea bed.

Possible Effects on Fisheries

Herring and Salmon are the two fish that would be most affected by wave energy converters west of the Outer Hebrides, the report states. The authors note that these waters are some of the most productive especially for herring, which spawn in this area on gravels and rely on currents to carry them around the North coast. The authors state that the wave energy converters beyond 10km offshore are unlikely to have much effect on herring larvae but that were the converters to produce small alterations to the currents, this might have an effect. On balance they conclude that wave energy converters would be unlikely to have any significant effect on herring, but further information on drift currents and behaviour of herring larvae is required.

The report states that salmon which migrate long distances might be affected by a long line of wave energy converters. Noting that salmon are important as a commercial resource, the authors state that migration routes probably cross the proposed line of wave energy converters and since salmon swim fairly near to the surface, they may be obstructed by the converters. Predators such as birds and seals might prey on salmon forced to swim between converters.

The report considers other fish such as cod, haddock, saithe and Norway pout and shellfish unlikely to be affected by floating converters, though converters fixed to the sea bed would have considerable effects.

Navigation

Wave energy converters would present a hazard to shipping especially since they would not be very visible to eye or radar, being low in the water, the report states. The main effects in the Outer Hebrides are considered to be to fishing vessels, with collision and formation of rougher seas the main risks. Converter positions would need to be marked with warning lights and radar reflectors and gaps in the converter line, up to 2km wide for shipping lanes would need to be made, the report states. Hazards to small vessels from rougher seas caused by reflection of waves from the converters would require an exclusion zone around the converters, it states. A compensation noted is that there would be calmer water on the shore side. The report mentions that the possibility of oil developments in the area would increase the conflicts with shipping lanes though other wave energy converter locations eg off the coast of Scilly would be more affected.

Economic and Social Development

In a section on the human and economic effects, the report states that the Outer Hebrides area is characterised by a lack of large scale industries and a declining population. The large scale installation of wave energy converters could provide employment and possibly cheaper power for local industry. The authors state that visually, the converters themselves would not be a problem but construction and maintenance facilities and electrical transmission lines might have to cross the island of Skye with associated visual impact.

The report acknowledges that at the time (1978) the state of development of the technology prevented greater precision about the requirements for shore based facilities, eg between the desirability of electrical or chemical energy carrier transmission.

This report identified the main issues to be investigated should a wave energy programme be implemented, but its limited scope could not begin to identify environmental constraints in any more detail, and in the absence of any full scale prototypes there has been no confirmation.

Nature Conservation

A report by the Nature Conservancy Council '*Nature Conservation Implications of Siting Wave Energy Converters off the Outer Hebrides*' on the environmental implications of siting wave energy converters off the Outer Hebrides, covers much of the same issues as Energy Paper No 42 but in greater detail and with a more academic approach (NCC 1979).

This work was part of the same programme of wave energy Research & Development. The report examines the possible effects on natural habitats and wildlife of the area particularly with regard for implications for nature conservation. Topics covered are the natural history of the Outer Hebrides, nature conservation there, wave energy conversion and effects of wave energy devices. Another version of this report was published as a paper in Ocean Engineering in 1983 including the Moray Firth as a wave energy location. (Mitchell 1983).

Under natural history, the report contains details of the species found in the area, eg fish, marine mammals and sea birds, as well as the types of shoreline, rocky or particulate shores, beach and sand blown complexes. The report states that the latter are important since behind the beaches the dunes may give way to 'machair' which are sand blown flat land areas and are also the best farming lands in the Outer Hebrides.

The report notes that there are seven Grade 1 (most important sites) nature conservation sites in the Outer Hebrides and eight Grade 2 sites, (Mitchell 1979) with St Kilda National Nature Reserve and Grogarry Lochs designated as Biosphere Reserves under the UNESCO's Man and Biosphere Programme, and Grogarry Lochs recognised under the Ramsar Convention. Most of these designations relate primarily to bird life.

Types of Wave Energy Converter

The section on wave energy converters lists and describes many of the designs then current eg the Salter Duck, Cockerell Raft, Oscillating Water Column, Russells Rectifier,

Submerged Duct, and Flexible Bag. The converters would consist of massive concrete or steel structures.

Effects of Wave Energy Converters

The effects of wave devices removing energy might include altering water mixing and stratification which may affect the primary productivity of the waters. However, the authors state that this appears to be controlled mainly by tidal mixing and so wave converters are likely to have only a minor effect on existing patterns. (Edwards 1977, cit in Probert & Mitchell 1979). They state that temporary diversions of heat would occur but the cooling of the water would be too slight to be of biological significance. (Salter et al 1976, cit in Probert & Mitchell 1979).

The authors state that main result of a line of devices would be wave modification with medium waves altered most since longer period waves will be transmitted largely unaltered and short period waves will tend to be reflected. Wave exposure is, the authors state, a prime factor governing coastal morphology and the composition and abundance of species of intertidal and subtidal communities. They note that the Outer Hebrides' shelving sea floors are rich with flora, eg the extensive *Laminaria* forest, though it is possible that offshore floating devices would not alter the flora any more than long term natural fluctuations. Inshore sea bed mounted devices however, would they believe produce significant wave changes resulting in changes to flora, eg a decline of *Alaria esculenta* and the appearance of *Himanthalia elongata*. The report states that increased shelter on their leeward side and expected deposition of sediment would lower *Laminara* production and there might be bigger populations of the sea urchin and limpet. (Picken 1978, cit in Probert & Mitchell 1979).

The report notes that the Hydraulics Research Station calculated that for floating offshore converters, wave steepness would be unaltered or slightly reduced. However, Allen argues that if most of the energy of constructive summer waves is removed by the converters, but powerful steep waves are left unaffected, then the beaches would adopt a storm or winter profile, with extensive coastal erosion. If the onshore sediment movement were interrupted the report states, there might be important consequences for the wind blown sands and the maintenance of the important machairs. Residual currents in the area which are biologically important are mainly tidal, though there is evidence that the waves generate a pattern of currents flowing in a different direction. However, the authors acknowledge, the data is scant on these subjects, .

New Habitats

New habitats might be formed by the converters themselves, as wrecks, oil platforms, and artificial reefs attract flora and fauna the authors suggest. Fixed devices on the sea floor in 15-25m depths, in particular would cause deposition on their shoreward side, they state. However, they point out that fouling of the devices would need to be controlled since it would cause increased drag, corrosion behaviour changes, and hinder inspection and maintenance and antifouling could be a source of environmental impact with the slow release of toxins. Some plants, the authors state, eg *Laminara*, could foul the intakes of certain converter designs.

Noise

In bad weather devices will be noisy, the authors state and inshore devices will tend to be audible from the shore. They note that underwater noises carry for long distances (HRS 1977 cit. in Probert & Mitchell 1979) and may be important to fish marine mammals and maybe invertebrates. The lower frequencies appear to be the significant ones, they state though data is lacking.

The report covers similar themes to Energy Paper 42, effects on fisheries, harbours, and workforce but in greater detail. On the subject of power transmission, the adverse effects on birds of pylons and cables on S.Uist are considered. Undersea cables would be used between the Outer Hebrides and Skye.

The authors conclude that no major deleterious effect on the marine environment are at present foreseen by floating wave energy converters. Fixed devices though, they state, are likely to have greater effects. Wave energy and fisheries are not incompatible in the Outer Hebrides they state. They remark that the Outer Hebrides are outstandingly important for nature conservation as well as being a scenically attractive area, and developments will need to be controlled. They suggest that any new developments should be sited near existing population centres and state that major developments in the machair would be undesirable as the ecology there is fragile.

However, they note that the timescale for a wave energy development on this scale, a 200km line, would be about 30 years giving adequate time to monitor ecological impacts.

ETSU's R 26 report '*Wave Energy*', covers the same ground to Energy Report No 42 in a very brief form (ETSU R26 1985). However, its conclusion appears to be the opposite to that of ETSU 42 and the NCC, stating that "the conclusion reached was that exploitation of wave energy may not be environmentally benign".

Onshore wave energy devices would of course have different effects and the paper below mentions this, though impacts to nesting birds, visual impacts, or construction impacts are not mentioned.

Falnes and Lovseth in a general overview of wave energy include a little on environmental issues. (Falnes & Lovseth 1991). On shore plants will, the authors state, require some irrevocable encroachment on the land topography, though offshore plant will have little visual impact. They state that the dampening effect of wave energy converters will give a sheltering effect and if devices are built into breakwaters, this can be significant in reducing shore erosion, or for shipping technical operations or for recreational areas. For fishing, they believe the effects to be equally balanced between more sheltered waters and obstructions, but they state that fish farms could benefit.

The positive effects of wave energy converters in providing shelter are also stated by Salter.

Salter, in an edited version of a paper on wave energy briefly covers some aspects of environmental impacts from wave energy, '*Wave Energy Some Questions and Answers*', (Salter 1993). He states that the Norwegian Tapchan system has a major impact but one in particular that several potential purchasers value more highly than the energy output, - that it can provide safe clean play areas in places where the coast would otherwise be too dangerous for recreation. On the issue of noise from wave devices, Salter considers the "deep slow heavy breathing noises" of present designs of oscillating water columns, "soothing and interesting". Though he notes that some devices have a high pitched component, most onshore or inshore devices he states, require relatively deep water ie a rocky shore, not beach siting, and so would be unlikely to obtrude on recreational activities. He comments on the other impacts which have been reviewed above and does not consider them to be significant barriers to wave energy exploitation.

Langford comments on the relationship between waves and currents, and associated shore shapes. He states that for tidal conditions, the movement and settlement of substrate material depends on the angle of collision between coastline and waves, as well as the depth of water and geology of local rocks (Langford 1984). He states that waves usually strike obliquely, moving finer materials along the coast. Sand and finer material are he states, deposited in sheltered bays or inlets where waves tend to hit the shore at right angles.

Conclusion

Wave energy converters will almost certainly have some impacts, though these are relatively undefined compared to other renewable energy technology. Concern as to effects on long shore currents and coastal features may prove to be the most serious. Undoubtedly environmental effects will constrain wave energy to some extent, so that shipping can continue, and beaches are not adversely affected. Onshore devices are likely to affect some cliff and rock dwelling birds or other fauna. Generally the human domain will be unaffected, but the physical impacts may be more significant. However, low level deployment of offshore devices may have few adverse effects.

Table 9 Summary of Impacts from Wave Energy

Landuse / use of space

On shore.

Planning / Compatibilities

Shipping Lanes, inshore fishing, cable routes.

Noise

Wells & other air turbines create high pitched whistling/ breathing sound.

Visual

Onshore devices can be prominent. Offshore might not be visible at 10 km distance.

Safety

Wave conversion devices drift from mooring in storms ?

Wildlife

Anti fouling coating.

Loss of some water oxygenation ?

Geomorphic Effects

Loss of waves in median range ?

Change to winter time wave erosion beach shape due to storm waves not stopped by device but normal summer waves absorbed ?

Long shore currents changes?

Ocean Thermal Energy Conversion

A brief review of a paper representing the very small amount of literature available on this topic can be included here.

OTEC technology employs temperature differences between the surface of oceans and lower depths in tropical regions, to achieve a potential difference which can be harnessed to generate power. Generally, cool water is pumped up from a depth where 25° C temperature difference can be found. OTEC devices are either closed cycle where a working fluid such as ammonia or freon is used in conjunction with a rankine cycle heat engine or open cycle where the cold water pumped up is the working fluid. This is condensed under a partial vacuum and the vapour used to drive a turbine.

Quinby-Hunt describes the physical and ecological impacts in a paper '*Potential Environmental Impacts of Closed Cycle Ocean Thermal Energy Conversion*' (Quinby-Hunt 1987). He states that closed cycle OTEC systems could result in atmospheric releases of working fluid, attraction of biota, while local fogs could be caused by the upwelling of cold water. Alteration of sea surface temperatures is another concern mentioned by the author, and climatic alterations may result, he states, from small sea surface temperature changes spread over large areas. However, he cites Bathen, that a 100MW plant would have no significant effect on surface temperatures. In addition he states that release of CO₂ is a concern, as gas solubility decreases with increasing temperature. However, he does not appear to describe the effects of discharge of nutrient rich cold water, as has in fact been observed at a pilot OTEC plant in Hawaii, though he does state that effects on nutrients need to be evaluated.

Chapter 8

General Environmental Impact Literature

In this chapter a selection of some of the less specialised literature on environmental impacts of renewable energy sources comparing impacts is reviewed in order to begin a synthesis.

1. Holdren et al

Holdren et al 1980, in a much quoted and in some respects, far seeing paper '*Environmental Aspects of Renewable Energy Sources*', set out to consider what information is required for comprehensive comparative assessment of environmental effects of energy alternatives, summarize the technological characteristics of the most promising renewable energy technologies, emphasising how they cause environmental problems, compare renewable energy technologies to each other and with non renewable energy technologies, and offer suggestions for the implications of energy choices.(Holdren et al 1980).

The introduction begins with the subject of externalities, which are costs to the environment not traded in the market place and external to the activity, in this case of energy production. Holdren et al state that "the environment is central to the energy problem not peripheral", and that the "energy problem consists of steering a course between the economic consequences of too little energy and the environmental consequences of too much energy". They state that their perspective rationalises the possibility that society will choose to pay more in monetary terms for a more benign energy source, than a less benign one. In their view, although a large literature on environmental impacts from renewables exists, there is a problem that like is not compared with like.

The paper describes the elements of a systematic environmental assessment, with the steps to aid communication of the complexity of the problem of causal linkages listed as:

- Origin of Environmental Effects,
- Insults to immediate environment
- Pathways by which insults lead to stresses
- Stresses, -altered environmental conditions
- Damages, -response of components to stresses

A complete analysis would they state, contain information of :

- distribution of damage in space and time
- ease of control of damage
- degree of irreversibility
- how the damage scales
- degree of uncertainty

But they acknowledge that such complete information is not available even for the most studied energy technologies. The processes linking insults, to pathways and stresses and their relation to damages "pose the most intractable problems in environmental science."

They emphasise the dangers of supposing that the most quantified forms of environmental harm are the most important - ie recognising only what can be measured. The key characterisation of renewable energy, the point that current fuels are concentrated whereas renewable energy flows are diffuse, is made, and that this results in greater land and materials usage. Another very important point made is that renewable energy flows power the environment and the biosphere and "large enough interventions in these natural energy flows and stocks can have adverse effects on essential environmental services."

The paper contains a summary of the impacts from renewable energy technologies: passive and active solar, solar thermal electric, photovoltaics, terrestrial and orbiting satellite, wind, hydro and OTEC. The authors consider hydro to be arguably the worst option due to damage to ecosystem per unit energy and the increasingly scarce ecological resource - 'free flowing rivers'. The authors consider the question of environmental effects from big new dams versus small ones undecided. Passive solar was considered to have the least environmental effects.

However, they note that "catalogues of potential environmental effects are of limited usefulness without measures of relative severity". They suggest some basic measures:

- Land Use
- Water Use
- Non Fuel Materials
- Occupational Accidents & Diseases
- Public Risks from Accidents
- Effects of Routine emissions on Public Health
- Effects on Climate
- Ecosystem Effects

By technology, wind energy has according to the authors a significant land use but this decreases per unit with scale. The relation of HEP to land use has not demonstrated. For Biomass smaller units have better land use.

The use of water is greatest in biomass, mainly in bioconversion.

Non fuel materials use is greater for renewables than for fossil fuels, but according to the authors, economic pressures will lead to pressure to reduce material consumption.

The paper states that much data is available from different energy technologies on occupational accidents and disease but suffers as a measure, due to incompleteness with conceptual problems and deficiencies and the problem of drawing boundaries. However, the authors suggest that the occupational effects for all stages of renewables could be equal to total occupational effects from coal.

Only large Hydro and orbiting solar satellite technologies are considered to pose significant public risk from accidents. The effects of routine emissions on public health are considered to apply mainly to biomass burning and water quality.

The authors describe the four ways climate effects are caused: 1) altering atmospheric properties, 2) surface to atmosphere interface, 3) Adding to Climatological energy flows, fossil and nuclear fuels mobilising energy from long term shortage, 4) Redistributing natural energy flows, if exploitation of renewables increased by a very large factor. For fossil fuels, CO₂ emission and decreases in ozone are the most important. Biomass is considered to have the most significant effect on the climate due to surface reflectivity

moisture transfer and air pollutants, though non sustainable use of biomass would contribute CO₂ emissions.

Generally, the environmental effects of dispersed renewable are considered to be only local. However, if large scale deployment of centralised renewable energy sources occurred, the effect of redistribution of energy flows might become appreciable, they state. On the subject of ecosystem effects the authors believe that concern over damage to ecosystems are based on "reverence for nature and related ethical and aesthetic considerations", but that considering damages to ecosystems seriously "does not rest on these intangible issues alone."

They state that ecosystems provide goods and services that contribute to human well being, eg nutrient recycling, soil formation, water storage and flow regulation as well as maintenance of a genetic library, (biodiversity). However, although there is a large body of observational data on ecosystems, they consider that few general principles are known. This is due to the "tremendous complexity and stochasticity of such systems which makes prediction of human induced stresses extremely difficult". Comprehensive comparison of different energy technologies is therefore at a necessarily very primitive stage being qualitative rather than quantitative."

From qualitative characterisations of different technologies' interactions with the ecosystem, HEP and plantation and forest residue biomass pose, in the authors view, the greatest threat per unit of energy, together with perhaps, OTEC and orbiting solar satellite technologies.

In conclusion the authors admit that their coverage of the subject is incomplete, omitting aesthetics and sociopolitical issues as well as certain technologies such as tidal, wave and geothermal. In their view, the environmentally attractive renewable technologies are passive solar heating and cooling, HEP at existing dams, wind, and biogas. The much less attractive renewable technologies are they think, new HEP, Orbiting Solar Satellite, and intensive biomass plantations. Most of the other renewables are likely to prove superior environmentally to coal and oil, they believe. In their opinion, "the greatest asset of decentralised renewables may be their tendency to impose their main environmental burdens on the users of the energy or on those the users must compensate, in contrast to fossil and nuclear sources whose environmental costs are imposed on groups far removed in space and time." They believe this will permit users to decide how much energy and which sources to use, and how much is enough.

2. OECD

The OECD Compass Project Report 'Environmental Impacts of Renewable Energy' is a compendium of the impacts of renewables in a fairly succinct form. (OECD 1989).

The authors view is that "renewable energy technologies can in general be considered as more environmentally favourable than most other sources," but they do have different impacts. They state that because "renewables tap more dilute energy flows which are generally of a more physical rather than chemical nature, the impacts of renewables tend to be physical rather than chemical." The issue of renewables' larger land take and materials inputs requirement than concentrated fossil fuels is reiterated. But there are, they state, important positive aspects of renewable energy use; "renewables generally imply more localised, shorter term environmental effects".

A comprehensive range of renewable energy technologies is considered in the report. The principle ones are passive solar, solar thermal electric, solar active, solar photovoltaic, wind biomass production and conversion, geothermal, hydro, and various ocean systems.

The principle impacts according to the authors are airborne, waterborne, solid wastes, land and material requirements, subsidence, visual intrusion, thermal discharges, public and occupational effects, health and safety, changes to the biosphere and noise.

Fairly detailed summaries of the impacts of each technology are given, but the authors state that "at present, methodological tools to enable a truly rigorous analysis ...are not available." They believe this is due to the inability to identify system boundaries which are particularly problematic for renewables.

Renewables they point out, still have important environmental impacts which are often unforeseen for new technologies. A section on potential contributions from renewables to world energy resources and market shares is included. The technologies and their impacts are then described in turn.

The authors state that the impacts of renewables can be mitigated but "unfortunately, past experience suggests that the full impacts of renewables are only recognised after adverse effects have reached significant levels, because insufficient attention has been given to predicting harmful effects in advance, and remedies incorporated into the maturing technology as an integrated system." The authors accentuate this important principle and describe their approach, identifying the impacts, as constructive.

The report does not attempt to rank impacts in order of gravity, nor has any attempt been made to present costs and benefits because of difficulties with system boundaries, geographical and temporal boundaries, and type of damage, and degree of knowledge. Other social and institutional impediments to renewables and benefits from exploiting them are included.

3. Watt Committee on Energy

The Watt Committee on Energy, an influential group of commercial and academic energy specialists, published a comprehensive report in 1990 *'Renewable Energy Sources'* concerning the current status of the technology and prospects for exploitation in the UK (Watt Committee 1990). This report considered in addition, environmental impacts of energy production, both as a stimulus to renewable energy and as a barrier. The authors state that renewables are popularly thought to be an environmental improvement but are not free from other objections. "Renewable sources can reduce pollution by displacing conventional thermal generation in electricity supply, but will not have a significant effect for many decades to come unless the government force the slow pace of take up." However, renewables can introduce environmental impacts of their own, eg visual intrusion, noise, radio interference from wind turbines, toxic emissions from biofuels, interference with fish populations and water flow from mini hydro, conflict of land use and other disturbance to the natural habitat, the authors state. But significantly they note that "no satisfactory method of comparative assessment in this area exists".

In a discussion on energy policy they acknowledge that environmental considerations in energy politics have become more important due to the effect of global warming and climate change through CO₂ emissions and other greenhouse gases. Renewable energy

technologies "thus find themselves in a most encouraging position as far as RD & D policy in IEA member countries is concerned".

The report describes the technologies and their status for each different source with a short section at the end on environmental aspects. On the subject of tidal energy, the authors state that the Severn barrage scheme would save 700m tons of coal over its lifetime. The scheme would be safe, they note, with its environmental impacts limited mainly to the estuary, so having considerable benefits as well as impacts. For wind and wave energy, the impacts would generally increase with increases in the scale of the development.

The comments on environmental impacts from hydro electric schemes seem somewhat contradictory; the authors note that run of river schemes proposed in recent years by NSHEB "had run into environmental opposition to add caution to estimations of potential". They also claim however, that "the environmental impact of hydro electric power schemes is entirely local to the installation", yet among the impacts they include interference to migratory fish, water diversions and water flow and quality downstream. Impacts that both Petts and Langford (reviewed earlier), cover, together with effects on deltas, riverloads, salt water incursion etc, which are all felt a long way downstream not just in the locality.

The authors state that Geothermal energy might be considered a benign source compared to fossil / nuclear energy but has adverse environmental effects. OTEC is described as one of the most benign of the renewables in environmental impact terms.

For solar energy, their view is that there appear to be no significant environmental barriers to widespread adoption of the active solar technologies.

Biomass is described as either a benign technology or not depending on 'exponents'. Plants are described as a diffuse energy source. Direct combustion the report states, releases large quantities of particulates and polycyclic hydrocarbons but much less SO₂ than fossil fuels. CO, CO₂, NO, and SO₂ are all emitted in small amounts but aldehydes, formaldehydes in greater quantity than for fossil fuels. Biomass pollution from animal wastes can be effectively treated by anaerobic fermentation, resulting in solid residue useful as a fertilizer, the authors note. They warn however, that soil impoverishment is possible through overuse of biomass conversion. Liquid pollution can result from some biomass conversion. The example of sugar beet and cane conversion to produce alcohol is given. This leaves an average 910 litres of residual liquors per ton processed which is highly polluting with a high B.O.D. of $5-10 \times 10^3$ ppm, and has a high metal content with potassium levels of 1-4.6 kg K₂O per m³. However, industrial uses for the effluent do exist the report states.

The CO₂ effects of using biomass are mentioned and it is pointed out that replanting on a large enough scale could 'soak up' CO₂.

A section of the report, devoted to environmental impact, summarises impacts from the renewables so that qualitative comparisons can be made between renewable and conventional energy sources. However, the authors state that they have not included the environmental effects of mining and processing materials nor the energy content of conversion systems. The term 'environmental pollution' is defined as the effect of any human activity on our world which is considered detrimental. The effects are considered

under the categories of land, water, air, wastes, working fluids and gases, general effects and catastrophes. A large table shows the relative magnitude of the effects of the different energy technologies / sources, as small, medium or large. The table, emphasises the advantages of renewable energy showing, that no renewable energy technology has entries which match those of conventional energy plant, -the only impact which is greater than fossil or nuclear energy is land use, due, unsurprisingly, to its low energy density.

The question of the small uptake of renewables is addressed, being in the authors' view partly due to the failure of traditional market price mechanisms to reflect environmental advantages.

4. STOA

The European Parliament's technology assessment unit STOA, which provides expert scientific and technical advice to members of the European Parliament, has produced a report on the environmental implications of renewable energy. (STOA, 1992, 'The Environmental Implications of Renewable Energy Technology', Summary Report, Scientific and Technical Options Assessment, European Parliament.) The report questions whether a shift in energy supply to renewable sources would be completely benign. It concludes that it would not but states that nor could renewables be considered environmentally damaging in the conventional sense, eg for fossil fuels. The report summarises briefly the environmental impacts of wind, biomass, solar, tidal, hydro, wave and geothermal power, and includes a chapter on external costings of energy supply, while another chapter reviews the positive environmental effects of renewables. Although the assessments of impacts are fairly standard, not all the impacts of hydro appear to be mentioned, eg sedimentation effects, while the barely realised technology of wave energy is ascribed a formidable set of impacts, and solar photovoltaic is allocated the usual manufacturing impacts burden.

A summary of some external costs is included, quoting USA, German and UK work, these are reviewed in the next chapter.

The STOA report, in common with other commentators, concludes that impacts from renewables tend to be localised and very site specific, often being a matter of perception, and in general often avoidable. "Large scale systems such as hydro and tidal barrages can have very significant effects on the environment in terms of damage to ecosystems and human lifestyle". Only biomass fuel and geothermal energy suffers from airborne and waterborne pollutant emission, the authors state. While on the subject of wind energy, though recognising visual intrusion, they claim this "may not be such a great barrier to greater use of wind turbines". The authors contrast such systems with renewables such as passive solar which have few impacts. Summarising, the report states that all energy systems have associated environmental impacts, "using renewables would seem to offer a trade off of one type of pollution for another," those from renewables being local and small though still real.

5. UK ISES

More recently a conference on *'The Environmental Impacts of Energy Technology'* was held in May 1994 by the UK Solar Energy Society with papers on photovoltaics and the environment, the role of energy efficiency in reducing environmental impacts and

environmental cost assessment of conventional electricity generation (UK ISES 1994). Hill outlines many of the themes concerning external costs referring to some of the papers reviewed above. Twidell in a paper '*The environmental impacts of wind and water power*' proposes five categories of environmental impact: physical, chemical, biological, ecological, and aesthetic and describes how the impacts of energy technologies differ significantly. He includes reference to energy flux density at first capture, as a factor strongly influencing physical and aesthetic impacts but does not develop this very much, apart from noting that hydro power has 100 times the energy flux density of wind and solar and that another factor is efficiency of conversion. Twidell in fact adopts a similar approach to that of Clarke (1993).

Other relevant literature includes the TERES European Renewable Energy Study, (TERES 1994) and PACE Environmental Costs of Electricity, (PACE 1991) which however are primarily focussed on developing valuation and costing methodology and are reviewed in the next chapter.

Chapter 9

Costing of Environmental Impacts

Introduction

This chapter briefly reviews a small selection of the literature about the costing of environmental impacts from different energy sources, including renewables. In the previous chapters the physical impacts and some of the social impacts of renewable energy sources have been described. This chapter considers some of the methods used to value and cost these impacts so that they may be translated into economic behaviour that minimises environmental and social costs. This is an extensive and difficult subject area with considerable philosophical ramifications and much ongoing debate and so can only be discussed superficially here.

Cost Benefit Analysis

This type of analysis is the basic means of attempting to identify costs and benefits that may not be expressed in market prices. Cost benefit analysis attempts to measure in money terms all the benefits and costs from a project or activity, and to allow the project if the sum of the benefits exceeds the sum of the costs by a sufficient margin (Methods Guide 1982). It is included here since it forms the basis of all the methods described below. Areas where it may be applied are often in the public domain, or are external factors not usually included in conventional market economics such as environmental and pollution issues. Intangibles such as the cost of health or even a life or very long term issues may be valued economically in the process of costs and benefits analysis. Although cost benefit analysis will aim to include all the effects likely to result from a project or activity, in practice this is impossible, and a boundary must be set on the effects identified. Where this boundary is set will inevitably affect the outcome. Identification of the social groups affected is required as are techniques for valuing in money terms intangibles and this can also be controversial. The outcome is a summary table of costs and benefits. Although Cost Benefit Analysis has been criticised, it can allow comparison between projects or activities not usually transparently represented. Moreover it can be employed in many variants; the figures that are used can be weighted to convey other values and of course they can be disputed.

Methodologies

1. TERES.

The TERES '*European Renewable Energy Study*' contains a useful section on the Environmental Costs of Energy Technologies and the Issues of Valuation (TERES 1994). This begins with a brief summary of the rationale for monetary valuation of externalities. Since there are no property rights for most environmental functions, the report states, there is no trade in them and so no price. To prevent excessive demand on the capacity of the environment to assimilate pollution, prices can be set so as to take into account the full costs that are borne by society. Environmental resources can then be assigned to those users who most value them. "The costs and benefits of environmental services not traded

in the market place are termed environmental externalities, or environmental external costs".

Examples are given of air pollution effects , eg impaired health, visual impacts, damage to buildings, adverse impacts on natural systems. Valuation techniques have been developed to put a monetary value to these environmental externalities,

The methods of valuation are listed, the most common being;

- Contingent Valuation, which is described as the willingness of people to pay for changes to levels of environmental quality.
- Hedonic Pricing, where the differences in property prices are used as a reflection of differences in the quality of the environment.
- Travel Cost Method, which measures the amount people pay to travel to a site as an estimate of their willingness to pay for its quality.
- Measurements from Actual Markets, eg the impacts can be measured from costs of healthcare or other damage.

However, the authors state, there are a number of difficulties with this since environmental effects may have no natural units of measurement. Some are subjective rather than physically measurable, eg visual impact. Nor can environmental impacts necessarily be forecasted since natural systems involve extensive and complex mechanisms which may only become apparent over long times scales.

Over the last ten years, there has been significant progress made in the testing and development of techniques to assign monetary value to environmental effects, the report states. Dose-response relationships, the physical relationship between pollutants and environmental damage, understanding of connections between environmental changes and human perception and internal technical "reliability " problems, have all progressed significantly.

Some practitioners have used control costs (ie the cost of preventing pollution) instead of estimating damage costs, as a means of estimating damage values, since it is easier to estimate and can appear more real. But there is no real validity to this technique the authors state, since it involves no balance between costs and benefits.

2. PACE

There have been a number of attempts to value the externalities associated with energy the report states. The PACE University study *'Environmental Costs of Electricity'* is probably the most comprehensive. The report includes some estimates of the externalities of various energy sources, drawing on the PACE University studies, (PACE 1991).

A table showing some externality estimates for fossil fuel electricity generation is included.:

Externality	Cost (ECU/kg)	Coal		Clean coal		Gas		Oil	
		High	Low	High	Low	High	Low	High	Low
SO ₂	3.4	0.076	0.008	0.0092	0.0015	0.0	0.00	0.046	0.0061
CO ₂	0.011	0.011	0.010	0.011	0.0097	0.006	0.0051	0.011	0.009
NO _x	1.4	0.055	0.004	0.0024	0.0003	0.004	0.0002	0.004	0.0018
Particulates	1.97	0.036	0.0003	0.0018	0.0001	0.0003	0.0	0.003	0.0004
Total externality Cost (ECU/kWh)		0.178	0.022	0.024	0.012	0.010	0.005	0.064	0.017

Table 10 *Externality Costs due to Air Pollution from Fossil Fuel Power Stations (ECU/kWh).* (PACE 1991)

Another table of the calculation of conventional waste-to-energy plant emissions from the PACE report is included.

Pollutant	Cost (ECU/kg)	ECU/kWh
SO ₂	3.4	0.0115
NO _x	1.4	0.0061
HCL	0.2	0.0002
Particulates		
CO ₂	-	-
Total externality Cost (ECU/kWh)		0.0198

Table 11 *Calculation of conventional waste-to-energy plant emissions,* (PACE 1991).

The figures show estimated unit costs by emission and are the result of bringing together estimates of impacts and externality costs from published work. The TERES report warns that the figures must be treated with considerable caution and the full study qualifies the data.

The waste to energy plant external costs must also be set against the costs of waste disposal which would have to be performed in any case.

3. Hohmeyer

The same type of calculation has been carried out on the renewable energy technologies by Hohmeyer 'Social Costs of Energy Consumption' and a table summarising environmental costs for various renewable energy technologies is included below.

Technology Type	ECU/kWh
Solar	0 to 0.003
Wind	0 to 0.001
Biomass	0 to 0.006
Wastes-to-energy (incineration)	0.0198

Table 12 Social Costs of Energy Consumption (Hohmeyer 1988).

Once again caution needs to be used in relation to these figures since they may be calculated on the basis of subjective valuation of eg noise, and may only include some of the impacts. Estimates of external costs for hydroelectric, geothermal and sea power generation are not included due to lack of reliable data.

The environmental costs for renewable energy are on this calculation, much lower than for fossil fuels or for nuclear energy (which were also calculated in the PACE study), apart from those for wastes combustion, reflecting the high emission of airborne pollutants of this technology.

4. Discussion

The TERES report comments that the average generating cost in the EC is 0.04 to 0.05 ECU/kWh, while for example coal's external costs for air pollution 'High estimate' comes to 0.178 ECU. It summarises by stating that the positive environmental impacts arise from displacement of fossil and nuclear energy technologies and that renewables do not cause net CO₂, NO_x, and SO₂ to be released to the atmosphere. This reduces both greenhouse gas generation as well as acid precipitation. The negative impacts of renewables are generally localised and relate to physical factors such as visual intrusion, land take and potential disruption of ecosystems, which also apply to conventional power technologies, the report states.

Hohmeyer summarises some of his work on the external and social costs of energy in a paper 'Renewable Energy and the full costs of energy', in Energy Policy on the full costs of energy and renewable energy (Hohmeyer, 1992). In this paper he outlines some of the social and external costs of conventional energy sources such as the damage to forests from acid rain to the health effects of a nuclear accident such as Chernobyl. His list of other social and external costs includes:

- Impacts on human health, short term impacts: injuries and long term impacts eg cancer, and genetic damage.

- Environmental damage to flora and fauna; global climate; materials.
- Long term costs of resource depletion.
- Structural macroeconomic impacts such as employment effects.
- Subsidies such as R & D subsidies; subsidies in kind for : infrastructure and evacuation services in case of accidents.
- Cost of an increased probability of wars due to : securing energy resources (eg Gulf War); proliferation of nuclear weapons know how through the spread of 'civil' nuclear technology; costs of the radioactive contamination of production equipment and dwellings after major nuclear accidents.
- Psycho-social costs of : serious illness and death; relocation of population due to construction or accidents.

The list is he states, not exhaustive, but shows that very considerable costs are not borne by the producers or consumers, which are he calculates, in the range of 0.03 to 0.16 DM (1989 DM @ 1DM = £ 0.37), per kWh for electricity generation by fossil fuels.(Hohmeyer 1992). For nuclear generated electricity, the external and social costs are estimated at 0.1 to 0.7 DM/kWh.

The cost of renewable energy is considered by Hohmeyer in terms of the avoided social and external costs of present electricity generation; he cites total social net benefits for wind energy in the range of 0.05-0.28 DM/kWh even after taking negative environmental impacts into account.

Hohmeyer argues the case for adding the social and external benefits of using renewable sources to the price paid for them, as a premium price which would have the effect of speeding up their introduction and market diffusion rates. "An energy policy will be needed to internalize all social cost elements not presently included in energy prices to secure a sound future development of our energy systems and a sustainable development for mankind". While this could also be effected by imposing taxes or levies, if that is not feasible in the short term, an increase in the buy back rate paid for electricity from renewables could be a starting point.

A summary of some external costs is included in the STOA report reviewed earlier, quoting Bonneville Power Administration (BPA), USA, Fraunhofer Institute (1988), PACE USA (1990), and Ferguson UK work (STOA, 1992), This shows the divergence possible in using different assessment techniques, where external costs for renewables are estimated by BPA at 0-0.5c/kWh, (1989 US \$), and by Ferguson at 4-40p (UK) using contingent valuation methodology for wind turbines in an area of outstanding natural beauty. The Fraunhofer Institute figures, (presumed to be Hohmeyer) are estimated at 0.01 Pf/kWh for wind and 0.44 Pf / kWh for photovoltaics (1982 Deutsche Pf) and PACE estimated externalities at 0-0.4c/kWh for solar, 0-0.1c/kWh for wind and 0-0.7c/kWh for biomass, (1990 US \$). Some divergence of costs is likely due to differing environments, but different methodologies and assumptions are probably responsible for much of the variation.

The STOA report confers the usual environmental benefits of no CO₂, SO₂ or NO_x on renewables, and then gives figures for the potential savings in Germany, France, UK and Ireland for 5% penetration, or 15% of most prominent power stations with 10% of second

most prominent. In Germany 6% and 30% annual CO₂ emissions can be saved, in France only 2% and 7%, in the UK SO₂ savings are 9% and 31%, but only 0% and 8% in Spain, and in Italy 3% and 8% NO_x and in Ireland 3% and 16%.

5. Pearce

The report by Pearce et al *'The Social Cost of Fuel Cycles'*, shows how social costs might be converted to 'social cost surcharges' or externality adders, (Pearce et al, 1992). The authors state that the purpose of the report is to survey the available literature on monetary estimation of the social costs of energy production and use, focussing on electricity production. They consider both environmental externalities and non environmental externalities including renewables in the fuel cycles considered, along with coal, oil, gas turbines, and nuclear. However, the report states that most of the necessary data is as yet unavailable for renewables, apart from some values for occupational and public health and accident costs. Acknowledging this, the authors emphasise the illustrative nature of figures employed and point to the gaps in knowledge.

The report explains how adders might be used and how double counting is likely to occur with both costs added and benefits subtracted at the same time.

The three basic ways that adders may be used are listed:

- Ranking with Grandfathering: only new generating capacity ranked by social cost
- Taxation with Grandfathering: adder charged only to new capacity
- Complete Emissions Adder Taxation: all sources, old or new taxed by adder done by emissions or by monetary damage

The basic procedure standardising adders is, the authors state, through 'emissions' per unit electricity, grams SO₂ per kWh, and by monetary damage per unit of pollutant concentration, eg £s of building corrosion per tonne SO₂ deposited, the ambient concentration. Pearce et al warn that there are a large number of complexities with this method, such as the failure to relate damage from eg pollutants to their concentration, stating that most estimations are based on average damage from *all* existing sources. "Only a major research activity can identify the probability of marginal damage", the report states.

The authors explain the philosophy of externality adders stating that in the absence of markets, non marketed effects, need to be valued for externality pricing, and the report lists the familiar methods for valuation of environmental externalities and some others with brief explanations.

- contingent valuation
- contingent ranking
- travel cost method
- hedonic pricing

and also:

- avertive expenditures: based on willingness to pay for avoiding damage
- dose response methods: linking pollutant and damage, to eg costs of health (response)
- risk compensation : based on market compensation for risk, eg higher wages.

On the subject of monetary value and willingness to pay, the authors accept that wealthier individuals might be more willing to pay for eg good quality air. This they appear to consider is an inevitable consequence of market values. Other themes discussed are the problem of understated value of 'public goods' eg clean air, and risk perception, where the public may not have an objective perception, eg may believe the risk to be much greater than in reality. Discounting the future, where future damage, especially long lived, underestimates or undervalues the damage is also discussed. The report states that the discount rate does not play a significant role in externality adders in the study "because damage done by emissions are not 'located' in any specific period of time".

The authors believe that the basic philosophy of externality adders is sound, " -or at least is as sound as any alternative".

The transferability of values, ie "the extent to which valuations derived in one context can be applied to other contexts" , is described as perhaps *the* major issue at the moment.

Health and whether risk is voluntary or involuntary is debated. The problems of deciding what costs are already internalised are considered, -here the assumption is that all health damage is non internalised . The 'Value of a Statistical Life' is debated, with current values in the UK stated at about £2 million. The authors then cover the topics of Fuel Cycle Risk Factors showing a table, Nuclear Power Hazards: Routine Radiation, Accident Risks, damage to crops, and forests from ozone. Biological diversity is briefly touched upon and a section discusses damage to buildings and materials from SO₂, global warming damage estimates, land, water and visibility impacts. Non environmental externalities, where a subsidy for other social purposes such as energy security, are debated briefly by the report. Finally a table of 'best estimates' of Environmental Externality Adders is shown, see below, but as stated, most of the values are unavailable for renewables.

However, the authors note that "for tidal a potential biodiversity adder of 0.8p/kWh may be considered, although there is considerable uncertainty about this figure", which is based on displaced wildlife habitat estimates.

In conclusion the report recommends further work on acid rain economic impacts, global warming damage costs, dose response human health issues, accident costs, crops and forest impacts, buildings damage, and transferability of values.

The report is mainly concerned with emissions of fossil and nuclear, perhaps of necessity since most work has been carried out in these areas. While the methodology is clearly explained, the dearth of reliable data is illustrated by the recommendations for further work which seems to include most of the themes mentioned. A potential shortcoming with regard to renewables is the manner in which immature technology still under development may be allocated costs as though they were firm. This point applies also to variants of a particular mature technology eg clean coal, too. The criticism that in the absence of figures for a cost, the cost is not counted in any way, leading to distortion, has been made by other commentators.

Environmental Externality Adders
(p/kWh)

Fuel Cycle:	Old Coal	New Coal	Oil	Gas	PWR	Sol	Win	Hyd	CHP
EEs									
Health									
-mortality	0.32	0.32	0.29	0.02	0.01	0.07	0.04	0.03	0.03?
-morbidity	0.12	0.12	0.12	0.04	0.01	-	-	-	0.06
-disaster	NE	NE	NE	NE	(a)0.02-0.05 (b)0.27*	NE	NE	NE	NE
Crops	0.10	0.05	0.05	0.02	NE	NE	NE	NE	0.02
Forest+	0.84	0.07	0.98	0.03	NE	NE	NE	NE	0.03
Biod	NE	NE	NE	NE	NE	NE	NE	NE	NE
Builds	3.22	0.28	3.77	0.11	-	-	-	-	0.14
Noise	NE	NE	NE	NE	NE	NE	NE	NE	NE
GHGs x	0.40	0.34	0.35	0.16	0.01	-	-	0.01	0.17
Visib	NE	NE	NE	NE	NE	NE	NE	NE	NE
Water	NE	NE	NE	NE	NE	-	-	-	NE
Land	NE	NE	NE	NE	NE	NE	NE	NE	NE

[Notes: underlined figures are negative; *(a) uses the Rocard-Smets function which is linear in the number of people affected; (b) takes the 'square function' estimate for risk aversion and the value of a group accident; x takes the average of the range for GHG damage; -means zero; NE means not estimated and probably positive; + indicates that the upper bound has not been used.]

For landfill gas the EEs will tend to correspond to the values for natural gas.

For geothermal and wave power it has not proved possible in the time available to secure an overall adder profile.

For tidal a potential biodiversity adder of 0.8 p/kWh may be considered, although there is considerable uncertainty about this figure.

Table 13 'Best Estimates' of Environmental Externality Adders. Pearce 1992.

Chapter 10

Conclusions

Chapters 2-7 reviewed a selection of the literature of the physical environmental impacts of the different renewable energy technologies. Chapter 8 reviewed some of the literature presenting an overview of renewable energy's impacts and Chapter 9 reviewed literature of some of the ways in which impacts were used in energy policy.

Common Impacts

It can be seen from the review above of the literature of environmental impacts from renewable energy, that renewable energy sources have a variety of environmental impacts some of which are common to all renewables and others that are unique to a particular source. These impacts are summarised below.

Common Effects:-

Landuse / use of space
Planning / Compatibilities
Noise
Visual
Safety
Wildlife

Source specific effects :-

Geomorphic Effects (Hydro, Tidal, Wave)
Gaseous emissions (Biomass, Geothermal)
Liquid Emissions (Biomass, Geothermal)
Soil Effects (Biomass)
Drainage Effects (Hydro, Tidal)
Eutrophication (Hydro)
Subsidence (Geothermal)

Some of the impacts that stand out are given below for each source.

Hydro Electric Power has particular impacts which arise from substantially altering the river flow rate producing rapid fluctuations, especially if following demand, or 'peak shaving'.

Biomass Energy can have significant impacts from soil and water depletion, overproduction, species diversity and the scale of its collection and conversion plant.

Geothermal Energy has substantial impacts when operated in an open cycle mode.

Particular impacts from Wind Energy are related to the scale of developments and their proximity to human settlements.

Tidal Energy causes considerable changes, and can have marked impacts resulting from any interruption of the (altered) tidal regime, eg any out of course operation for demand following, maintenance or barrage closure.

Solar Energy has its greatest impacts from the concentration and scale of central thermal plant and the manufacture and disposal of large areas of collector photovoltaic panels.

Wave Energy appears to have particular impacts related to possible changes in beach erosion and deposition and to possible effects on long shore currents.

Ocean Thermal Energy Conversion can have impacts related to CO₂ emission, local concentrations of nutrient rich sea water, as well as to the scale of plant.

Table 14 Summary of Environmental Impacts from Renewable Sources

Wind	Solar		Biomass	
	Photovoltaic	Concentrator	Production	Conversion
Visual	Visual	Visual	Visual+	Visual
	Glare	Glare		
Noise				Noise
Electro Magnetic				
Safety	Safety	Safety		Safety
Wildlife			Wildlife+	
			Soil Effects	
			Water Req	
			Fertilizer	
Land-use	Land-use?	Land-use	Land-use	Land-use
Incompatibilities				Incompatibilities
				Emissions: gas, liquid, solid

Wave		Geothermal
On shore	Off shore	
Small Land Use	No land-use	Land-use
		Incompatibilities
Visual		Visual (some)
Noise		Noise
Wildlife ?		
Decreased erosion?	Sea bed effects	
	Long shore current effects	
	Sea flora fauna changes?	
Coast/cliff protection?	Coastal/ cliff protection	
	Shipping Hazard	
		Fluid contaminants poss.
		Subsidence possible.
		Minor earth movts. poss.

High head Dam & Lake	Hydro	Barrage	Tidal
	Low head/ Run of River/ weir		Tidal Stream
Lacustrine	Only small change	Semi Marine	Little/no
Env. Created	to river gradient.	Lacustrine Env.	change
Land Use	Small/no land use	Small /no land use	no land use
		Reduced Tidal Range	small effect on
			Tid.range
Incompatibilities	Few/none	Few/no incompatibs.	No incomp.
Reduced water speed	Smaller reduct. speed	Reduced/ raised	Small water
			speed reduct.
Wildlife Change	" "	Wildlife Change	Small Wldl'f ef
Siltation	Small silting	Siltation Possible	No siltation
Eutrophication	Eutrophication Unlikely		
Reduced species diversity ?	" "		No reduct.
Changed Species	Little change	Changed Species	Little change.
Water table effects	Little/no water table effect	Water table effects	No effects.
Drainage Effects	Less drainage effects	Drainage Effects	" "
Flow Changes downstream	" flow change	Tidal changes	Little change
		downstream	
Increased erosion downstream	"	Poss. incr. erosion	
Water Temp changes	Unlikely		
Nutrient loss downstream	Little nutrient loss		
Fish migration barrier	Less obstacle to fish mig.	Fish migration barrier	Insig. obst
Fish turbine strikes	Can be less	Fish turbine strikes	Less
Fish damage from pressure changes	Less	Fish pressure damage	Small effect
Flood protection+	Flood protection (less?)	Flood protection+	
Flow regulation	Flow regulation (less?)		
Often raised levels for navig.	Raised levels for navig.		
		Shipping Hazard	Small Hazard

Chronological Development of Environmental Impact Studies

The first environmental impact studies appear to have been carried out in the late '60s to early 70's period, associated with effects from hydro electric schemes such as the Aswan Dam and geothermal emissions. Improving standards from other energy uses, eg Clean Air Act in the early '60's and the realisation that alternative generating options were increasingly available probably led to the questioning of impacts from renewable sources. The literature reflects the increasing awareness that renewable energy technologies do have an impact, and is part of a trend of increasing environmental understanding. This accompanies at the same time, the encroachment of man's activities into most virgin territories and environments. Initially, because renewable sources have no fuel cycle and

differ fundamentally from conventional energy sources, they were considered to have no or few impacts. For example in the case of hydro electric power, the time lag in the recognition of its impacts may reflect this initial perception. The great advances that have occurred in the ecological and biological sciences since 1950 led to the emergence of the environmental sciences and studies in the late 1960's and 1970's, and has accelerated since.

The Role of Environmental Impacts in Development of Renewable Energy Technology

Design

From the review above of the literature, it can be seen that environmental impact awareness has influenced the development and design of the technology, though in differing ways for the different technologies. The earlier renewable technologies such as hydro and geothermal were developed to a state of technical maturity before environmental concerns had gained widespread acceptance. In the case of hydro, once the public became aware of its impacts, very considerable opposition to the technology arose. Subsequently such technologies have been 'retrofitted' with add-on features such as fish passes and modified flow control systems to overcome some of the objections.

Other technologies have still not yet reached any great degree of technical maturity, eg wave energy, and some of the solar technologies, yet their environmental impacts are being to some extent modelled in anticipation of their emergence.

Tidal energy on the other hand, has been proven and certainly reached a level of maturity, yet since so few full scale developments have been implemented, environmental impact studies for tidal schemes are pursued very largely on a 'modelled' basis. The feed back from such modelling exercises has been employed to modify scheme designs and this demonstrates a positive influence of environmental impact studies. However, the result is that a large literature exists but with little real confirmation of expected environmental effects. The reputation of tidal energy among the conservation bodies and the public probably suffers unfairly from the quantity of the literature and dearth of actual installations.

For biomass, a very large body of knowledge concerning production has been accumulated historically, -unsurprisingly so considering the age of forestry and farming, but there are still gaps concerning long term effects on soils. The innovations in biomass technology are largely in the area of conversion and here the technology development is to some extent responding to environmental issues. Some of the literature advocates biological conversion, ie biogas, rather than direct combustion, so that the organic compounds are not lost to the soil cycle. Yet the conversion methods employed for biomass can be so varied and result in many different fuels, gas, liquid and solid, that it is difficult to determine what influence environmental concerns are having on the technology development. Certainly combustion has gained a somewhat dirty reputation among environmental pressure groups.

The development of wind energy is possibly the most constructive example of the influence of environmental impacts and studies. In this instance, the recent development of the technology has been largely concurrent with recognition of environmental effects,

resulting in rapid incorporations of design changes to mitigate effects, such as noise reduction or siting and layout procedures. The nature of the technology with numbers of relatively small converters lends itself to this incremental design development whereas the very large structures necessary for some other technologies, eg dams and barrages would not. Wind energy's reputation has been influenced by the extent of publicity given to potential environmental effects and the depth of impact studies, which may have given a false impression. This has resulted in assertions that wind energy has big impacts, yet surveys of public reactions to *existing* developments show that wind energy is relatively popular.

Most of the solar energy technologies have few or small environmental impacts, yet this has not usually been a consequence of the influence of awareness of environmental effects, but due to the nature of the technology and the source. In the literature, it might seem that a misleading impression of the extent of some of the impacts has been given, eg the manufacture of photovoltaic cells, considering that all the technologies have impacts from manufacture.

To summarise, the influence of environmental impact awareness has post-dated some of the technologies, giving them a poor reputation, or pre-dated full scale development, again adding to environmental doubts, pre-dated the mature development of others, and only in perhaps one case has its influence been 'in phase' with the period of major technical development and thus been fully constructive.

Developments

The role of environmental impacts may be to allow or preclude a particular renewable energy scheme such as a wind farm, or it may preclude the development of a whole technology such as the Orbiting Solar Satellite concept. On the other hand environmental impacts may merely result a change in the project design, scale or siting in order to avoid or mitigate effects.

Thus the Process of an Environmental Impact Assessment can be seen as i) a sieve resulting in a yes or no to scheme go-ahead, and ii) an iterative design / modification process.

Environmental impacts have certainly had a substantial effect on implementation of schemes, where for example wind projects have been turned down due to impacts or public opposition. Wind sites have been altered, with turbines resited as have hydro and geothermal projects too. Even the relatively innocuous use of solar energy has sometimes been refused planning permission.

The Role of Environmental Impact in Policy

Given the different motivations for the development of renewable energy sources, eg at different times and in different countries, are environmental issues leading the development, or even very significant ? It may appear that environmental arguments are often used to support the development of renewables but in reality it is often economic arguments that are in control. This may apply in the case of the Scottish hydro power development, in the 1930's and 1940's times of fuel shortage or the Danish development of wind energy in the 1970's and 1980's after the oil price rises. However, some developments may well be more environmentally led, for example the German wind energy

development in the late 1980's and 1990's as a response to the International Conventions eg Rio, limiting carbon dioxide output. Positive environmental benefits, such as lack of emissions, are certainly used to justify subsidies or premium prices for fledgling renewable energy technologies. Sometimes, more local environmental impacts are incorporated into subsidy systems, with eg a bonus price for low noise emission wind turbines, (Ref German / Dutch subsidy wind energy see Energy Policy paper).

Although economic issues may seem to prevail, it must also be the case that many environmental issues become translated into economic issues. But this only occurs if the environmental issues are a) recognised and b) lend themselves to monetary valuation.

For example, the environmental issue of land drainage arising out of HEP or tidal energy schemes, will become an economic cost of the project. Loss of land space or quality, which is part of the human domain is readily identifiable and can be costed. Impacts on wildlife eg birds, and fish, often lie outside the human domain and so cannot be effectively costed in terms of human economic activity.

Therefore it could be suggested that environmental issues could indeed be driving the development of renewables on occasion, but only when they can be translated into the terms of human economic activity, ie monetary value.

Environmental effects from fossil and nuclear energy production have played the major role in justifying both support for the RD & D of renewables and their implementation, as the literature shows. Considerable subsidies are based on the rationale of environmental external costs etc.

The impetus for renewable energy can be seen as a:

- Response to oil crisis
- Response to need for generation diversity, alternative options, ie insurance policy.
- Response to environmental issues; global warming

Consideration of the character of the literature in terms of its source, -author or commissioner can illustrate these roles.

♦Characterisation of literature by commissioner / author

Envir. impact work carried out on behalf of :

- Government strategic research bodies
- Developers
- Nature & Countryside Conservation Bodies, Statutory & NGO.
- Planners
- Academic institutions

Govt. Strategic Bodies

Studies characterised by large scale, long term scenarios are aimed at providing an idea of overall potential of technology. These studies are usually carried out at a fairly early stage of development or implementation of the technology, at least in the country concerned. Such studies are usually general in nature and cannot and do not attempt to deal with the practical details of environmental impacts.

Examples are the early environmental impacts of wave energy by ETSU / Dept. Energy, also possibly some of the early environmental impact of wind energy studies.

The main aims of such studies appear to be early identification of barriers with a view to shortlisting for further studies. Initial characterisation of the subject and the identification of environmental impacts to discover whether any prove to significant or even immovable obstacles to implementation is an important step in development.

From the short listed topics, the second type of government funded work may be mainly for assessment of environmental barriers so as to refine resource assessments, and better target further publicly funded development efforts, eg Bell, Institute of Terrestrial Studies.

Environmental Impact Work by Developers

Such studies are usually characterised by a technical approach eg Swift Hook 's and also STPG's tidal barrage work.

It might be expected that such studies find environmental impacts to be surmountable, and that they do not represent a severe barrier.

Such studies are usually produced when there is a good chance that the technology will be implemented, ie when the technology is fairly mature.

These works are often very detailed especially of those impacts which are amenable to measurement and can be mitigated by technical modification. A somewhat even tone may be taken to the impacts, with no one impact predominating. There need be few value judgements since the overt purposes are purely technical. The aim is to develop the technology 's design and practice of implementation in the industry. Inevitably however, environmental impacts will tend to be peripheral to the technical development of the technology.

Nature & Countryside Conservation Bodies, Statutory & NGO.

Work on environmental impacts by such bodies will tend to reflect the concerns of their remits. Renewable energy developments are merely another type of development, one which has to be located in the countryside.

Such studies usually only appear when the technology shows clear signs of being implemented, again when the technology is fairly mature. In some cases the studies come after schemes have been sanctioned, eg wind, in others they may be in advance, eg tidal energy schemes.

As might be expected, the problems loom fairly large in such studies, although there is not usually the same even treatment of different impacts as the developers usually cover. Conservation bodies tend to select only one or two main impacts and then centre their concerns around these issues. Examples might be visual impact in case of wind, and the loss of mud banks for feeding birds in the case of tidal energy.

Statutory bodies will usually have to balance their arguments so as to reflect the multiple aims of their briefs, and also to acknowledge wider government policy.

NGO's have a more free rein to state the disadvantages in a less balanced manner. Eg 'triffling' descriptions of wind farms from the CPRE.

How often do such studies delve into detail, technical or otherwise and utilise academic skills ?

Generally, such studies concern themselves with policy issues, with govt. subsidies and planning policies. Economic issues may be briefly dealt with in a sceptical manner -eg "wind turbines are not worthwhile in terms of impact per kWhr versus the loss to amenity /landscape", a line adopted by some opposers of wind energy.

Planners

These studies are usually formulated for guidance for planning officers making decisions about individual schemes.

The prime concern will be to identify i) the character of these developments, so that a policy can be adopted for their

ii) development control.

Their technical interest will centre mainly around the nuisance created and they will not be interested in the technology per se.

By their remit planners will have to take a balanced view.

In the UK there is evidence of environmental impact studies by planning bodies coming somewhat late.

Academics

Works by academics can be pioneering leading the development of a new technology, anticipating its problems or they can appear when a technology is fairly mature and the issues can be consolidated and dealt with in a thorough and reliable manner. Examples of both types are included in this review. The two texts 'Impounded Waters', by Petts and Langford's 'Electricity Generation and the Ecology of Natural Waters', are texts for students, researchers, and practitioners in a developed field. Both tend to be painstakingly researched, highly detailed, and massively buttressed by surveys and statistical work all fully referenced.

♦Purpose of work or study

The Energy Technology Support Unit's reports for example are linked to resource and identification of 'barriers' to implementation, while Countryside Commission reports are linked to issues of protection of landscape as a response to a perceived threat. Local Authority literature, or the Government Planning Guidelines paper, are primarily concerned with planning.

Environmental Impact Work can be:

Technology led, -development of the technology itself provides new opportunities eg

development of new materials and new technologies leads to renewables technologies and designs becoming feasible and so to exploration of potential.

Or new technology leads to solution of environmental problems.

Environment led, ie as a response to fears from official / unofficial protection and countryside protection institutions, greater potential due to environmental advantages or disadvantages.

Local - Global. balance of environmental impacts of renewables.

EIA process, legislative,

Planning process

Economically led, ie extra costs and limitations of renewables, or lower costs / advantages and environmental consequences.

Policy driven, ie renewables as increasing diversity for greater security of supply. due to envir. disadvantages.

Resource study led, ie limitations on resource availability

Academically led.

Eg academic texts, and reports emanating from specialist research groups and departments set up in universities and research establishments. Are any advances in theory derived from this source propelling the subject forwards ?

■ **Final Comments**

Some key points emerge from this study.

These are :

- that no reliable methodologies for comparison between different energy technologies and external costs valuation exist
- the inadequacy of current definitions and analyses of natural environments
- natural energy flows power the natural environment
- the diffuse energy density of renewables

The pace of technological change may be another reason for lack of environmental studies' structure.

Lack of Reliable Methodologies for Comparison

There appears to be a consensus that no reliable methodologies for comparison of the different energy technologies exist. Holdren, OECD, Watt Report. Several reasons for this are suggested below.

As can be seen from the chapter above on costing of environmental impacts from all energy sources, attempts have been made to compare the impacts from renewable sources with those from fossil fuels. It is the belief that some of the impacts from the use of fossil

fuels are cumulative and irreversible as well as hidden in the current market price that has driven these costing and comparative studies. The purpose is to allocate externality 'adders' in the form of price so that the 'real cost' can be reflected in market price.

Unfortunately the means by which the impacts are valued and then costed are not standardised as has been recognised by Andrew Stirling (1993) and Eyre (1993). Nor are some of the domains within which the impacts fall amenable to valuing in a price form since monetary value is a function of the human world. Monetary value cannot be expected to value eg wildlife except in its function to the human world. The result of current costing exercises may be that they tend to compare unlike phenomena, and tend to be anthropocentric in nature.

The inadequacy of current Definitions of the Environment

In the literature, there is agreement that the extreme diversity and variety of natural environments defies attempts at analysis, and consistent structuring. As Holdren states, few general principles exist for natural environments and ecologies. Some commentators also cite the problem of system boundaries.

The literature usually lists the impacts rather than attempting to characterise them or model them. While this can describe local impacts for individual renewable energy schemes, it does not provide a true understanding of the operation of environmental impacts and their significance. The somewhat anecdotal nature of the description of environmental impacts from renewables and perhaps all energy sources, is probably to blame for the shaky basis of currently used costing methodologies. It cannot offer very much guidance to policy makers when choosing between different sources of renewable energy or directing overall technical development of the technology.

Confusion, often appears where for example, lists of impacts include social impacts as well as physical impacts. Holdren et al, write of an 'apples and oranges problem'. It would appear that the models of the environment employed are either simplistic or not soundly based. Identifying areas where currently practiced valuation techniques do work, and at what point they breakdown could enable system boundary discontinuities to be examined. The bringing together of a much more comprehensive and systematically defined notion of the environment, using multi disciplinary knowledge of a variety of sciences from engineering, physical sciences, ecology, and biology to earth sciences and geography and human sciences may be required. Defining the environment accurately should be a prerequisite for the development of sound models.

Environment powered by Natural Energy Flows

The literature recognises that the natural environment is powered by natural energy flows, and that this could potentially be a factor in environmental impacts, depending on the fraction of energy diverted (Holdren et al).

However, the literature does not, apart from that of HEP, (Petts and Langford) consider or analyse the *functions* of natural energy flows, and only general statements are made 'that the impacts natural environment is powered by renewable energy flows.

Energy Density

A number of references in the literature have drawn attention to the *diffuseness* of renewable energy flows.

However, although some of the themes above are repeated by several commentators, there does not appear to be any systematic investigation of these factors in the literature, apart from Clarke (1993).

Whether renewable energy sources are perceived to have lower environmental impacts than fossil or nuclear sources will inevitably depend on the valuation of those impacts as well as a simple listing. The scientific evidence that emerges as to the severity and rate of global warming as a result of CO₂ emissions, will inevitably affect the valuation of the impacts of fossil fuels. Likewise the impacts of low level radiation exposure and greater experience of nuclear wastes will influence the valuation of nuclear power's environmental costs. Other impacts such as acid deposition and ozone emission may also become better understood. So the question will to some extent depend on emerging substantiation and subsequent evaluation of impacts of commonly used non renewable sources.

However, it is the non human domains of the environment that pose the greatest problems in comparison and valuation, and some renewable energy sources tend to have a greater involvement and impact with these domains. From the literature reviewed above, it can be seen that different renewable sources tend to produce impacts in different domains of the environment and though impacts in different domains cannot be compared in like terms, comparative value judgements may need to be made for decision making. However, since many of the processes in each of these domains are reasonably well understood, if impacts are thoroughly enough defined and characterised, the significance may be fairly evaluated, though not perhaps in money terms.

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